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Sole: Production and markets

by

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The report undertakes an analysis of the production and marketing of sole through the introduction of a new sole farming technology with potential economic competitive advantages.

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EXECUTIVE SUMMARY

Landings of sole have declined over the last two decades. Due to its high price and declining landings, as well as a desire by farmers to diversify their operations, there has been substantial interest in the farming of sole in many countries for a long period of time.

The main objective of this report is to undertake an analysis of the production of and markets for sole. In terms of the capture fisheries, the emphasis will be on the North Sea, where the largest landings take place and the best data are available, but landings in other Atlantic areas and the Mediterranean will also be considered. Although there is much interest in the farming of sole, most of the literature is on biological and technical aspects of farming.

This report is to examine potential economic advantages of the new farming technology that has been developed and applied to sole farming. Firstly, for the farming technology developed, we will evaluate investment in a sole farm and associated cost of production through the basis of a model farm. A production plan will be established for this farm and associated investments will be considered allowing the cost of production to be analysed under different assumptions. Secondly, we will also examine the markets for sole. By combining analyses of cost of production and markets, we will be able to extract valuable information to be considered for future prospects of sole farming as it relates to the economic advantages of the farming technology under consideration.

1. INTRODUCTION

Sole is a high valued species much favoured in white tablecloth restaurants. Landings of sole have declined over the last two decades. Due to its high price and declining landings, as well as a desire by farmers to diversify their operations, there has been substantial interest in the farming of sole in many countries for a long period of time.

Landings and consumption of sole refer to two species: Common sole, also known as Dover sole (*Solea solea*, Linnaeus, 1758) and Senegalese sole (*Solea senegalensis,* Kaup, 1858). The two are almost indistinguishable to consumers and are often combined in production and market statistics. There has also been farming of both *Solea solea* and *Solea senegalensis* (Imsland *et al*., 2004; Bjørndal, 2014). Both from a farming and a market perspective, there may be advantages and disadvantages with both species. The two species are very similar, and the market may not distinguish between them.

The main objective of this report is to undertake an analysis of production of and markets for sole. This will include an analysis of sole fisheries in terms of landings and stocks. The emphasis will be on the North Sea, where the largest landings take place and the best data are available, but landings in other Atlantic areas and the Mediterranean will also be considered. In 2012, total - landings of sole in the North Sea amounted to about 17 000 tonnes of the almost 23 800 from the Atlantic Northeast, as compared to 2 200 tonnes in the Atlantic Eastern Central and 5 400 tonnes in the Mediterranean. However, the main emphasis of the report is sole farming taking into account its potential growth in the next few years, as well as markets for sole.

Howell (1997) points out that interest in the farming of sole has been stimulated largely by a desire, if not a need, for the existing marine fish farming industry to diversify. In particular, a revival of interest in the possibility of farming sole has been stimulated by indications of market saturation for species such as sea bass and sea bream. The consistently high price attracted by sole in European markets has repeatedly stimulated attempts to develop rearing methods for these species.

Dinis *et al.* (1999) point out that *Solea senegalensis* is a common high value flatfish in southern Europe, commonly reared in extensive aquaculture production in the Portuguese Republic and the Kingdom of Spain. In southern European countries, aquaculture production is concentrated on shore-based and sea pen cultivation of sea bream and sea bass. Due to high production, markets have begun to be saturated. Investigation of potential new species for aquaculture is one of the strategies for increasing market opportunities.

According to Imsland *et al*. (2004), scientific and technical interest focuses on high value native species whose biological cycle can be reproduced using currently available breeding techniques. From this point of view, *Solea solea* and *Solea senegalensis* appear as credible candidates for marine culture. According to Schram *et al*. (2006), Dover sole (*Solea solea*) is an interesting new species for marine aquaculture in Europe as it is a high valued species with a large market. García García and García García (2006) point out that sole aquaculture has attracted great interest in recent years, both at the research and the commercial level. This is particularly true in the Kingdom of Spain and the Portuguese Republic since the species' rapid growth and high price provide a tremendous commercial opportunity. Howell *et al.* (2009) point out that in Europe, the dominant species of interest is the Senegalese sole but there is still some commercial and research interest in the Dover sole (*S. solea*), particularly in more northern countries, notably the Kingdom of the Netherlands and the United Kingdom of Great Britain and Northern Ireland (UK).

Although there is much interest in the farming of sole (see, for example, Imsland *et al.*, 2004), most of the literature is on biological and technical aspects of farming. The purpose of this report is to analyse the potential economic advantages of the new farming technology that has been developed and applied to sole farming. First, for the farming technology developed, we will analyse investment in a sole farm and associated cost of production. This will be done on the basis of a model farm. A production plan will be established for this farm and associated investments will be considered. On this basis cost of production can be analysed under different assumptions. Second, we will also analyse markets for sole. Finally, by combining analyses of cost of production and markets we will be able to say something about future prospects of sole farming as they relate to the economic advantages of the farming technology under consideration.

The report is organized as follows. Section two gives an overview of sole fisheries as well as farmed production. In section 3, farming technology is analysed. In section four, cost of production in sole farming is analysed. Prices and markets for sole are considered in section five, while future developments are discussed in the final section. Background data are presented in an Appendix.

2. THE FISHERIES FOR SOLE

Sole is a long lived flatfish and can reach an age of over 40 years. Sole is a nocturnal predator and is therefore more susceptible to capture by fisheries at night than in daylight.

Two main species of sole are harvested: *Solea solea*, also known as *Solea vulgaris* or by the common name Dover sole, and *Solea senegalesis*. *S. solea* is mainly distributed in the North Sea and the Mediterranean; and elsewhere, southward to the Republic of Senegal. *S. senegalensis* is distributed in the Atlantic, from the Gulf of Biscay to the coasts of the Republic of Senegal; it is less frequent in the Western Mediterranean.

The two *Soleas* are very similar (Dinis *et al.*, 1999). Larvae of the two species are very difficult to distinguish. Both species are gonochoric, and females mature at age 3+ for *S. senegalensis* and 4+ for *S. vulgaris,* when total lengths are 32 cm and 27–30 cm, respectively. Female sole reach up to 40 cm after five years and a maximum length of 60 cm. Males rarely grow longer than 40 cm (Marine Conservation Society, 2014). Fecundity is very similar in both species. The life cycles are also similar. Southern populations of both species are characterised by greater asymptotic maximum lengths, indicating that they may potentially attain larger sizes in their southernmost ranges.

Sole is harvested both in the North Sea and the Mediterranean, but with most of the catches from the North Sea. In the following, we will first look at the North Sea and then give combined catches for the two areas. The catch statistics pertain to *S. solea*. As for *S. senegalensis*, catches are negligible[1]. After looking at capture production, we will look at farmed production in section 3.

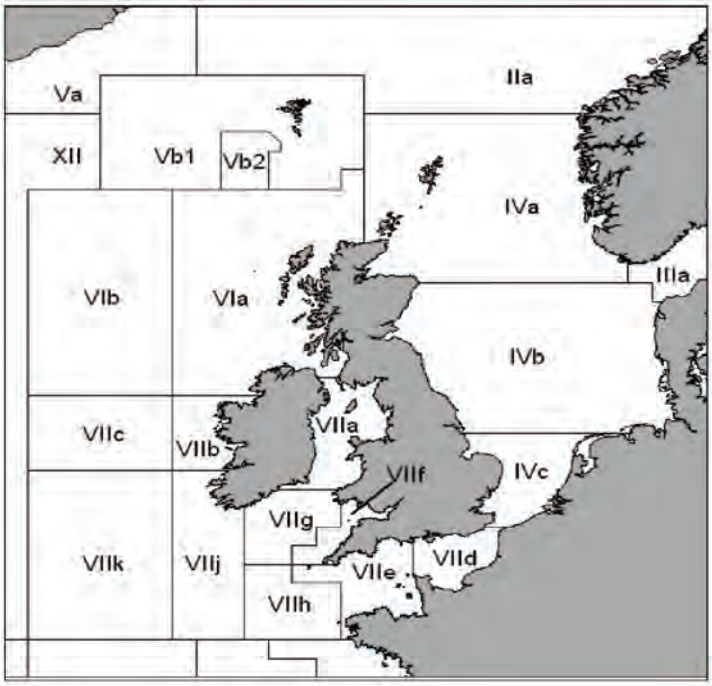
2.1. NORTH SEA

The North Sea is the northernmost border of the distribution of this species. In cold winters it withdraws to the deeper, warmer waters of the southern North Sea. A map of the fishing areas in the North Sea is presented in Figure 1. Sole is harvested in the “main” North Sea (Subarea IV), as well as the English Channel (Divisions VIId and VIIe) and Skagerrak (Division IIIa and subdivisions 22–24). An annual total allowable catch quota (TAC) is set for each area which in turn is allocated to national quotas according to the principle of “relative stability”.

As *S. solea* is a fairly stationary species, it is reasonable to believe that sole in European waters belong to more than one population (Imsland *et al*., 2004). The main spawning for *S. solea* takes place in the second quarter of the year in coastal areas close to the nurseries.

[1] Between 2003 and 2012, annual catches of *S. Senegalensis* varied between 31 tonnes and 89 tonnes (source: FAO Fishery Statistics 2012 – Capture Production).

Figure 1. ICES fishing areas in the North Sea



Source: International Council for the Exploration of the Sea: www.ices.dk/aboutus/icesareas/ICES_areas_Arc9_300.pdf

A two stage management plan for sole and plaice was agreed upon by the EU in 2007 (Council Regulation, 2007). The first stage was considered a recovery plan, with the second stage being deemed a management plan. The objective of the second stage is to manage the stock on the basis of Maximum Sustainable Yield (MSY).

The stock of sole in the North Sea (Subarea IV) is deemed to be within safe biological limits when the spawning biomass exceeds 35 000 tonnes and the average fishing mortality at ages two to six years is less than 0.4 per year[2]. The objective of the first stage is to ensure the return of the stock to within safe biological limits. This is to be attained by reducing the fishing mortality until the safe biological limit is reached (Rijnsdorp *et al.*, 2012). Thus, restrictive TACs are set to gradually reduce the fishing mortality. The multiannual plan shall, in its second stage, ensure the exploitation of sole on the basis of maximum sustainable yield.

An evaluation by the International Council for the Exploration of the Sea (ICES) concluded that the management plan is precautionary (ICES, 2010). The implementation of the plan varies by area, as we shall see below. The sole fishery is regulated by annual total allowable catch quotas (TACs). In addition, there are other regulations such as effort and technical restrictions. Minimum landing size is 24 cm for all areas while there is a minimum mesh size of 80 mm for beam trawlers. Local regulations restricting certain gear and vessel type are also in place. Sole is harvested by several gear types with beam trawlers being most

[2] Council Regulation EC No. 509/2007.

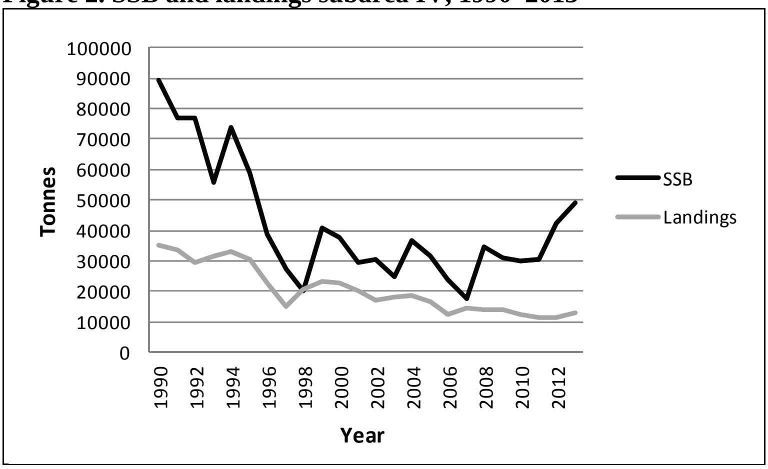
important. In many areas sole is harvested as part of a multispecies fishery. Inshore fisheries are important in some areas.

2.1.1. Subarea IV (North Sea)

Subarea IV is by far the most important fishing ground for catches of sole. Figure 2 gives annual spawning stock biomass (SSB) from 1990 onwards. The highest SSB was observed in 1990, with almost 90 000 tonnes; only in the early 1960s was SSB significantly higher, exceeding 110 000 tonnes. The peaks in the historical time series of SSB correspond with the occasional occurrence of strong year classes. Due to a high fishing mortality the SSB declined during the nineties to 20 000 tonnes in 1998. It recovered to 40 800 tonnes the following year. Subsequently, SSB has been quite variable, however, with an increasing trend since 2007, reaching almost 48 900 tonnes in 2012 and 89 000 in 2013. The SSB (and landings) have in recent years been dominated by the 2005 year class. The effect of the 2005 year class is now, however, starting to decline. The 2009–2010 year classes, which entered the SSB in 2012–2013, are above average.

The decline in the fishing mortality starting in the mid-2000s coincides with a reduction of capacity in the beam trawl fleet. High fuel prices have contributed to the decrease in effort and, consequently, of fishing mortality (Abernethy *et al*., 2010; Cheilari *et al*., 2013).

Figure 2. SSB and landings subarea IV, 1990–2013



Source: ICES Advice June 2014. See Table A1 in the Appendix for detailed data.

According to ICES[3], the stock level denoted MSY $B_{trigger}$, which warrants management intervention, is 35 000 tonnes with an associated F_{MSY} of 0.22. Moreover, B_{lim} is estimated at 25 000 tonnes while B_{pa} is 35 000 tonnes[4]. SSB has fluctuated around the precautionary reference points for the last decade and is estimated to be well above B_{pa} in 2013. Fishing mortality has shown a declining trend since 1995 and is estimated to be close to F_{MSY} in 2013 (0.232). The stock is above MSY $B_{trigger}$ and has full reproductive capacity; it is also above target for the management plan.

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[3] ICES Advice June 2014.

[4] B_{lim} is the minimum safe SSB level while, according to the precautionary principle, the stock should not be reduced below B_{pa}.

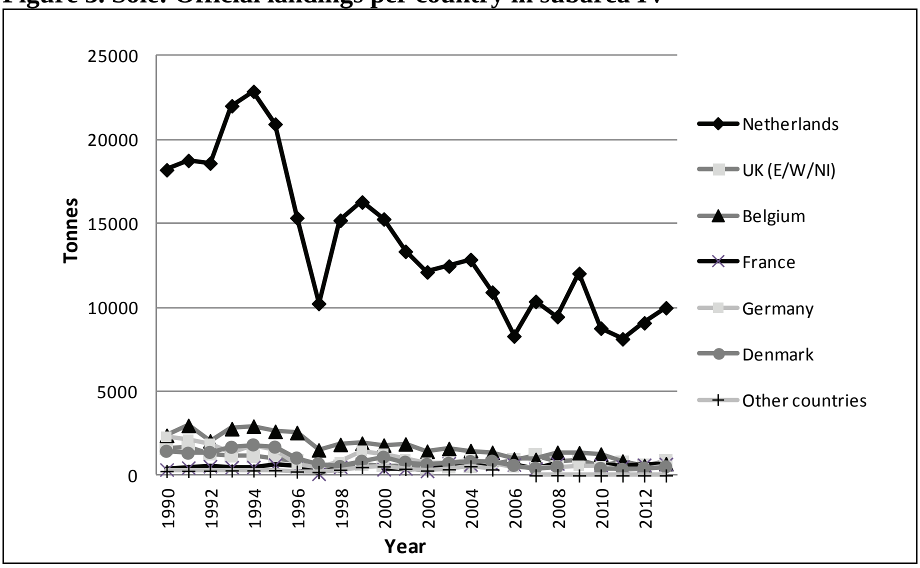
Annual landings have shown a downward trend over time, although there are substantial variations from year to year. In the years 2006–2013 annual landings have varied between 11 500–14 600 tonnes. Since 2005, total landings have not exceeded the annual TAC (Appendix, Table A2). However, between 2000 and 2005, landings exceeded the TAC, in particular in 2003, when the TAC was exceeded by 13 percent.

As noted above, there is a two stage management plan for North Sea sole. The sole stock has been within safe biological limits in the last two years. According to the management plan, this signals the end of stage one. Application of the plan is on the basis of transitional arrangements until an evaluation of the plan has been conducted.

Sole in the North Sea is mainly caught by the beam trawl fleet working with 80 mm mesh mixed with other species. An increasing number of the traditional beam trawl fleet is switching to sumwing and/or pulse trawl. Other directed fisheries for sole are carried out with gill nets and otter trawls. Bycatches of sole in other fisheries are small.

The Kingdom of the Netherlands is the dominant country in the fishery, often representing 70–80 percent of the total reported catch (Figure 3). In most years, the Kingdom of Belgium is the second most important country. The Kingdom of Denmark, the French Republic, the Federal Republic of Germany and the UK account for most of the remainder.

Figure 3. Sole: Official landings per country in subarea IV



Source: ICES Advice June 2014. See Table A2 in the Appendix for detailed data.

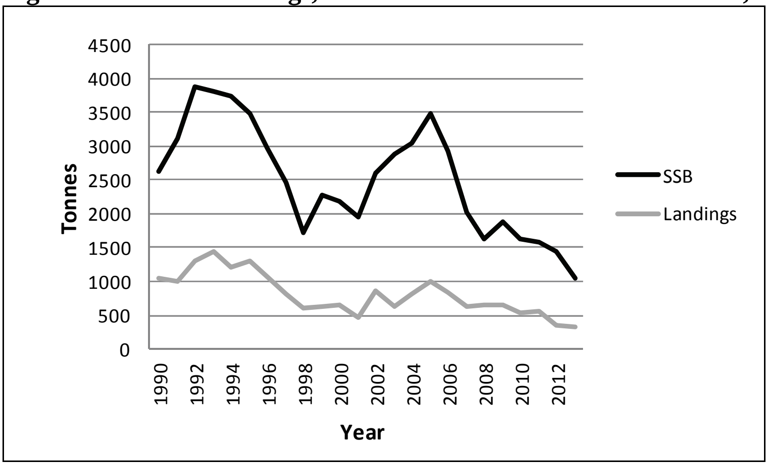
2.1.2. Division IIIa and Subdivisions 22–24

The SSB in Division IIIa and Subdivisions 22–24 (Skagerrak, Kattegat, and the Belts) has undergone substantial variation over time, with several peaks and troughs (Figure 4). One observes peaks of 3 812 tonnes (1993) and 3 492 tonnes (2005); since the latter, the stock has shown a downward trend, with 1 037 tonnes recorded for 2013.

According to ICES[5], MSY $B_{trigger}$ is 2 000 tonnes with an associated F_{MSY} of 0.30, while B_{pa} is undefined. SSB has decreased since 2006 and has been below MSY $B_{trigger}$ since 2008. Fishing mortality has been around 0.36 since 2005. The last strong year class was the 2000 year class; since then recruitment has decreased to a historical low recruitment in 2013.

Sole is taken in a mixed trawl fishery with nephrops, plaice and cod, the main season being in autumn-winter. In addition there is a directed gillnet fishery for sole, mainly in Skagerrak in spring and summer. After 1996, annual landings have varied between 500 and 1 000 tonnes, with a decline in recent years. Since 2012 annual landings have been less than 500 tonnes; in 2013, landings of 332 tonnes were recorded. Most of the catches are by Danish fishermen; however, their share in the total landings has been decreasing in recent years – in 2013 they represented 78 percent of the total (Appendix, Table A4).

Figure 4. SSB and landings, Division IIIa and Subdivisions 22–24, 1990–2013



Source: ICES Advice June 2014. See Table A3 in the Appendix for detailed data.

The ICES advises on the basis of the transition to the MSY approach that catches in 2014 should be no more than 353 tonnes. Discards are considered low. Even with this TAC, the SSB is expected to remain below MSY $B_{trigger}$ in 2015.

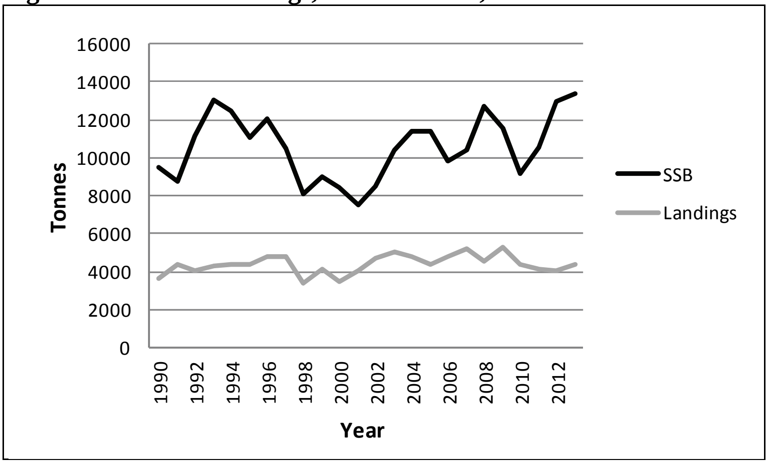
2.1.3. Division VIId (Eastern Channel)

The SSB in Division VIId has shown great variability without a particular trend; however, the SSB has shown an increase in recent years from 9 125 tonnes in 2010 to 13 370 tonnes in 2013, the highest observed in the data series (Figure 5). Landings have been relatively stable, fluctuating between 4 000 and 5 300 tonnes from 2001 (ICES catch; see Appendix).

According to ICES[6], MSY $B_{trigger}$ is 8 000 tonnes and so is B_{pa}, while F_{MSY} is 0.29. The SSB has been above MSY $B_{trigger}$ since 2002. Fishing mortality has always been above F_{MSY}. Recruitment has been fluctuating without a trend.

[5] Source: ICES Advice June 2014.
[6] Source: ICES Advice June 2014.

Figure 5. SSB and landings, Division VIId, 1990–2013



Source: ICES Advice June 2014. See Table A5 in the Appendix for detailed data.

Sole is mainly caught in 80 mm beam-trawl fisheries with plaice or in mixed demersal fisheries using otter trawls and gill/trammel nets. There is also a directed fishery during parts of the year by inshore trawlers and netters on the English and French coasts.

Under-reporting of catches and misreporting of sole into Division VIId and Division VIIe was thought to be significant but this is now less of an issue. The French Republic records the highest landings in Division VIId, followed by the Kingdom of Belgium and the UK, with 65 percent, 22 percent and 14 percent, respectively, of ICES catch in 2013 (Table A6 in the Appendix). Inshore vessels (under 10 m) on the English and French coasts target sole in spring and autumn. The inshore vessels take half the reported landings and sole forms their main source of income.

The basis for management advice is the transition to the MSY approach, i.e., stage two of the management plan. The stock is then considered to have full reproductive capacity.

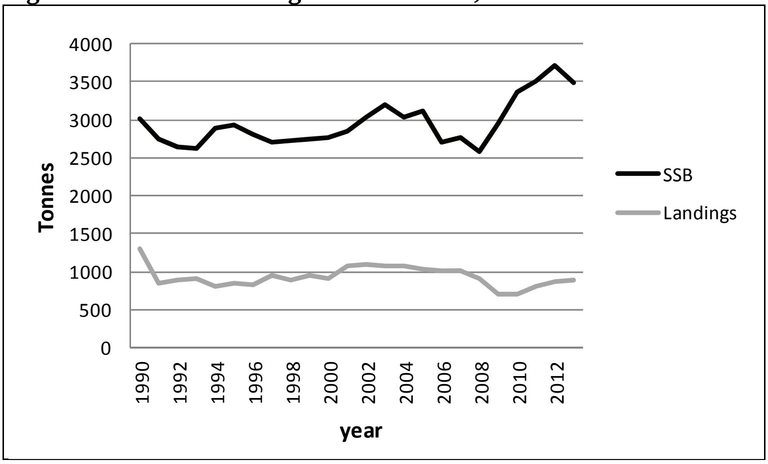
2.1.4. Division VIIe (Western Channel)

The SSB in Division VIIe increased from 2 432 tonnes in 1969 to a peak of 5 300 tonnes in 1980, the highest level ever recorded (Bjorndal and Munro, 2012). Since 1990, the stock has shown variability (Figure 6). Spawning stock size declined from 3 198 tonnes in 2003 to 2 590 tonnes in 2008, the lowest level ever recorded. In the period 2001–2007, annual harvest exceeded 1 000 tonnes which does not appear to have been sustainable. After 2007, annual harvests have been at a lower level with 882 tonnes in 2013, and the stock has shown some recovery. In 2013 the SSB stood at 3 489 tonnes.

According to ICES[7], MSY $B_{trigger}$ is 2 800 tonnes with F_{MSY} 0.27 and B_{pa} 1 800 tonnes. SSB has been around MSY $B_{trigger}$ for about two decades, with an increase since 2009. Recruitment has been fluctuating without a trend. Recent year classes, since 2010, are estimated to be below average. The stock is deemed to have full reproductive capacity management now based on stage two of the management plan.

[7] ICES Advice June 2014.

Figure 6. SSB and landings for Area VIIe, 1990–2013



Source: ICES Advice June 2014. See Table A7 in the Appendix for detailed data.

The principal gears are beam trawls, otter trawls and gillnets. Sole is the target species of an offshore beam trawl fleet in a fishery that also takes substantial catches of other species. Otter trawlers and gillnetters take sole mainly as a bycatch, although there is also a fishery targeting sole at spawning time. Discarding of sole is considered low. Sole is widespread and usually taken in conjunction with other species to varying degrees. The most productive fishing grounds are located close to port.

The UK has the largest share, with 60 percent of the TAC (ICES, 2014; see Appendix, Table A8, for landings by country). In the the UK, sole is harvested by several gear types but with beam trawlers taking the largest catches. This fleet is currently undergoing restructuring to reduce capacity. This is aimed primarily at vessels that traditionally target sole in the Celtic Sea and Channel.

Management of this stock is mainly by TAC. In 2005 effort restrictions were implemented for beam trawlers. These restrictions have not been limiting this fishery despite the decommissioning scheme, due in part to the large number of days available, but also because there appears to be some latent effort overcapacity in the the UK beam trawl fleet. Since November 2008 the the UK has been enforcing a single area licensing scheme which has been effective in reducing UK catches. gillnets are the only other gear with effort restrictions, but because of the nature of the fishery days at sea restrictions are ineffective. The management regulations implemented on the sole fishery in this area include TAC, days-at-sea restrictions, minimum landing size, and minimum mesh size. Local regulations restricting certain gear and vessel types are also in place.

Sole in area VIIe is probably the only sole fishery that has been subject to economic analysis and bioeconomic modelling. Bjørndal and Bezabih (2008, 2010) estimated the cost of harvesting for beam trawlers based on data spanning the 2001–2005 period at GBP 3 per kg, a cost that is fixed and invariant with the use of effort. This cost per kg takes into account variable and fixed costs, including depreciation and a normal return on capital. The price of sole was increasing from about GBP 7.00/kg in 2005 to about GBP 8.00/kg in 2006. In other words, net profit per kg harvested was quite substantial.

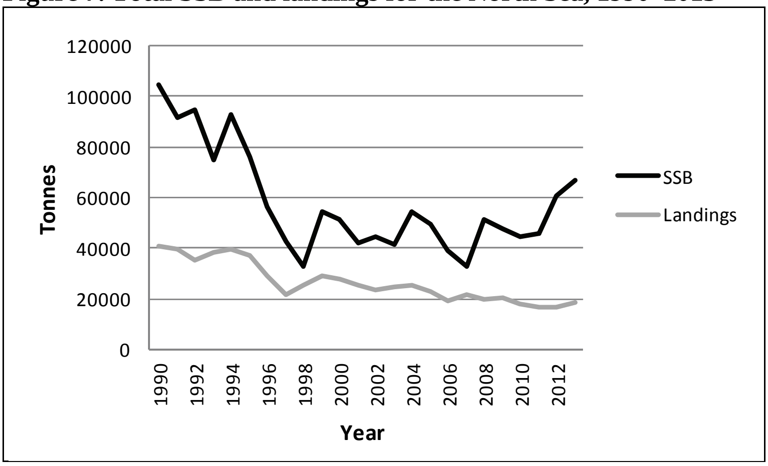
As reported in Bjørndal and Munro (2012), the optimal stock level is 5 100 tonnes (based on a discount rate of 3.5 percent). This calls for a very substantial *investment* in the stock, which can only be achieved by reducing harvest below natural growth for a period of years. This investment could give rise to fairly substantial rents in the fishery, provided fishing effort is kept under control.

It should be noted that most vessels harvesting sole also harvest a number of other species. Thus, the economic performance depends on the status and management of several stocks. Nevertheless, sole is in economic terms by far the most important stock for these fishermen.

2.1.5. Total fisheries landings

Aggregate spawning stock biomass and landings per year for the four Northeast Atlantic areas under consideration are given in Figure 7.

Figure 7. Total SSB and landings for the North Sea, 1990–2013

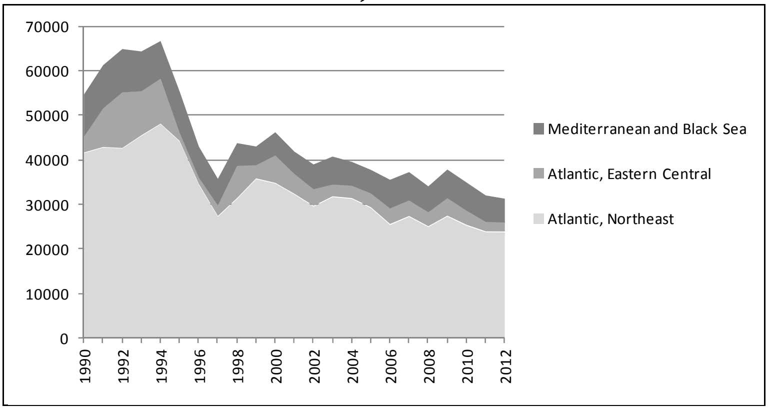


Source: ICES Advice June 2014. See Table A9 in the Appendix for detailed data.

As for SSB, the development reflects that of area IV (Figure 2). The largest SSB – 104 490 tonnes - was observed in 1990. Subsequently, the stock was in overall decline to a minimum level of 32 574 tonnes in 1998. Since then, there has been substantial annual variation; however, in recent years the SSB increased from 32 542 tonnes in 2007 to 66 767 tonnes in 2013. Landings show an overall decline over the period from 41 123 tonnes in 1990 to 18 742 tonnes in 2013.

In the Mediterranean, sole is part of multi-species multi-gear fisheries. On the whole, sole catches by themselves are relatively small and vessels rely on a large number of species for their revenues and profitability. However, there are some artisanal vessels that from time to time can catch about 100 kg a day, especially between August and October (Lleonart, Maynou and Salat, 2013).

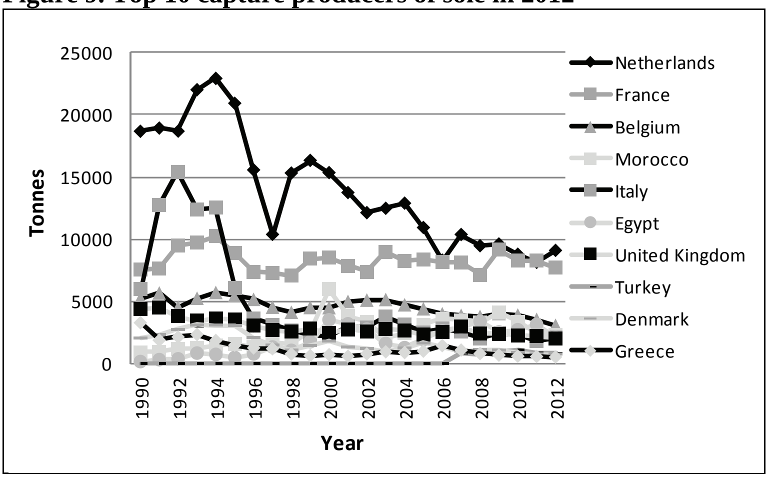
Figure 8. Annual capture production of sole in the Atlantic Northeast, Eastern Central and the Mediterranean, 1990–2012



Source: FAO.

The catches of the top 10 producers of sole as of 2012 are illustrated in Figure 9. Throughout the period the Kingdom of the Netherlands recorded the highest catches, declining from 20 900 tonnes in 1995 to 9 100 tonnes in 2012. Dutch landings in 2012 represented 28 percent of the total sole landings. The trend is very much in line with overall catches (Figure 9). The French Republic is the second most important harvester, but with a much more stable harvesting pattern than the Kingdom of the Netherlands. Catches in 2012 were 7 700 tonnes, 23 percent of the total sole landings, only slightly lower than those of the Kingdom of the Netherlands. The other important countries in the North Sea are the Kingdom of Belgium and the UK, with 3 000 and 2 000 tonnes in 2012.

Figure 9. Top 10 capture producers of sole in 2012



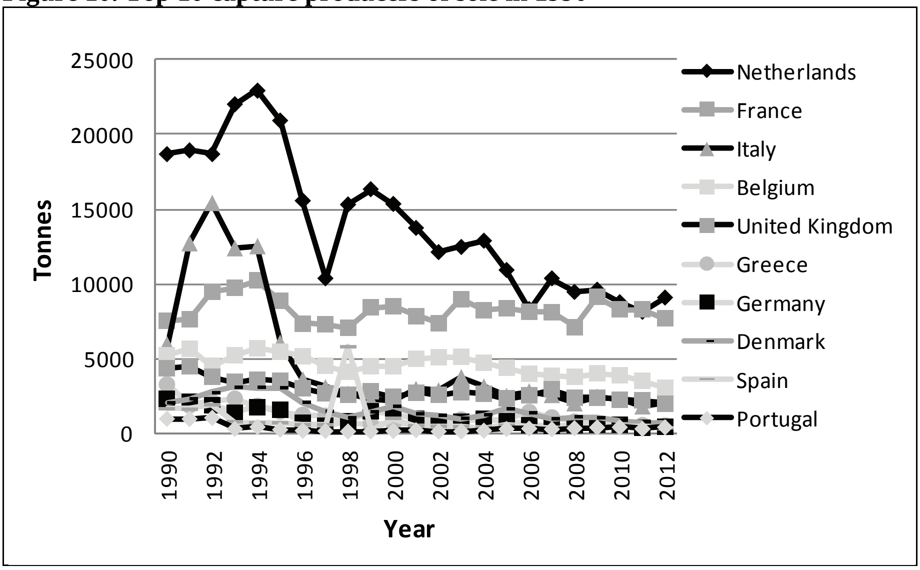
Source: FAO.

The Kingdom of Morocco, the Republic of Italy, the Arab Republic of Egypt, the Republic of Turkey and the Hellenic Republic are the most important harvesters in the Mediterranean, with 2 270, 2 080, 2 060, 790 and 510 tonnes respectively. Sole landings from Southern Mediterranean countries have increased significantly in the last two decades: Egyptian catches increased from 500 tonnes in 1995 to 3 100 tonnes in 2011, decreasing to

2 060 tonnes in 2012; landings from the Kingdom of Morocco were about 880 tonnes in 1990; while they were almost zero for the Republic of Turkey until the second half of the 2000s.

Indeed, this increase in the landings from southern Mediterranean countries can be seen when comparing Figures 9 and 10, and Table A11 in the Appendix. The catches of the top 10 producers of sole as of 1990 are illustrated in Figure 10. For the main producers in the North Sea – the Kingdom of the Netherlands, the French Republic, the Kingdom of Belgium and the UK – the picture is the same as in Figure 10. In the Mediterranean, however, there have been changes. In 1990 the Republic of Italy was the most important country with a harvest of almost 6 000 tonnes. By 2012 this had been reduced to 2 080 tonnes, and the Kingdom of Morocco with 2 270 tonnes had replaced the Republic of Italy as the most important country. The importance of the Arab Republic of Egypt and the Republic of Turkey has also increased, achieving 2 060 and 790 tonnes, respectively.

Figure 10. Top 10 capture producers of sole in 1990



Source: FAO.

3. AQUACULTURE PRODUCTION OF SOLE

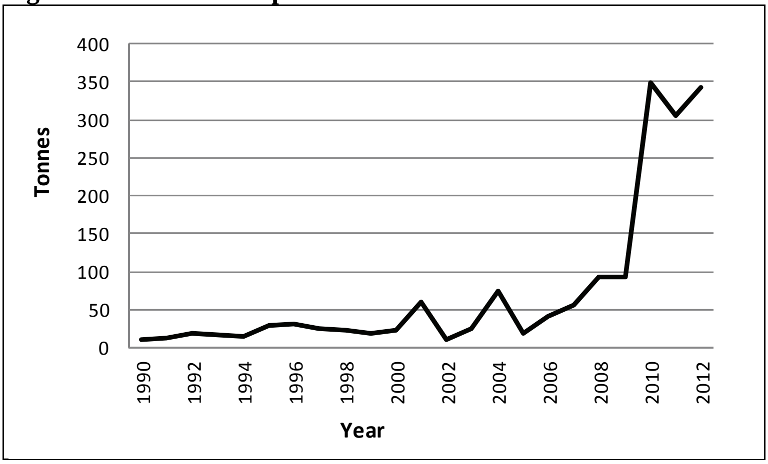
Sole is a new aquaculture species in Europe (Imsland *et al*., 2004). In the last three–four years an expansion in farming of Senegalese sole has taken place with ambitious plans for further growth. Most of the expansion has been within three companies with production facilities in the Kingdom of Spain, the Portuguese Republic, the French Republic and the Republic of Iceland. Within the next 3–4 years the production may exceed 5 000 tonnes. Almost all production, actual as well as planned, takes place with shallow raceway system technology in combination with re-circulation aquaculture system (RAS).

It appears that in the coming years almost all farmed sole production will come from Senegalese sole, in part due to better growth at higher temperatures than for common sole and since it takes place in southern European countries where Senegalese sole is found. Senegalese sole (*Solea senegalensis*) is a flatfish of high commercial importance that is indistinguishable by consumers from common sole (*Solea solea*), so it is rated as the same species in marketing statistics. Sole is a species which enjoys high acceptance by the consumer and which generally fetches high commercial value in European markets. Thus, what the consumer perceives as sole is actually a mix of two almost similar species, Senegalese sole and common sole.

Although interest in farming Senegalese sole intensively in southern Europe dates back to the early 1980s, it has failed to reach successful commercial development until recently. The reasons for this include lack of full control over spawning, poor fry quality and high mortality rates during the weaning stage, all leading to juvenile scarcity for stocking purposes. In addition, in the middle of the last decade, severe outbreaks of disease caused an early set-back for the first producers of Senegalese sole. Bacterial infections were the most important and frequent problems diagnosed as Pasteurellosis caused by *Photobacterium damselae* ssp *piscicida.*

Farmed sole production was 11 tonnes in 1990 and 30 tonnes in 1995 (Figure 11). Although there was variation from year to year, production did not start to expand until 2007 with a production of 55 tonnes reaching 349 tonnes in 2010, down to 306 tonnes in 2011 and up to 343 tonnes in 2012. In 2012, the French Republic produced 200 tonnes of *Solea senegalesis.* In the Kingdom of Spain, 65 tonnes of *Solea solea* and 85 tonnes of *Solea senegalesis* were produced in 2011, but only 95 tonnes of Senegalese sole and none of common sole in 2012. In 2012, the production of common sole in the Portuguese Republic increased to 45 tonnes. In addition, minor quantities were recorded for the Republic of Italy and the Hellenic Republic (see Table A12 in the Appendix).

Figure 11. Farmed sole production



Source: FAO.

The implication of this is that currently almost all sole commercialized comes from wild harvest.

3.1. SOLE FARMING TECHNOLOGY

Perhaps one important reason for this new trend observed is the sharp increase in research and development (R&D) on the species in the Kingdom of Spain and the Portuguese Republic at the turn of the century. Much of the research has focused directly on topics of great importance for the commercial production of the species. The key challenge has been the lack of success with natural spawning of the cultured sole species, thus closing the door to genetic programmes on the species. This situation has changed in the last few years[8].

For companies with an interest in farming of Senegalese sole, an overwhelming amount of literature from the last 10 years is available and it gives answers to the most pressing questions related to subjects such as maintenance of brood-stock, egg incubation, larval rearing and protocols to achieve mainly high quality female juveniles for on-growing with use of super-intensive farming technology. An initiative was taken by Dr. Bari Howell at the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) in the UK when he organized the first Sole Workshop in 2002 in Weymouth, England. At that time commercial interest in the farming of Dover sole or Senegalese sole was close-to-zero. In parallel with the successive workshops, interest from both scientists and commercial companies increased (Howell *et al*., 2006, 2009, 2011).

3.1.1. Reproduction

Reproduction of Senegalese sole has been one of the main obstacles to its domestication. There are severe problems in obtaining fertile spawning from the first cultured generation of individuals, called F_1 (Oliveira *et al*., 2011). This has become a huge drawback, as

[8] Most of the text is based on the Introducion to the doctoral thesis of Pablo Sánchez Fernández (Sánchez Fernández, 2012).

brood-stock has to be collected continuously from the wild, as they gradually lose reproductive performance in captivity.

Spawning of wild-caught brood-stock takes place naturally in tanks, primarily from March to July, with a secondary spawning in autumn. The egg fertilization rate is around 45–80 percent. Mating behaviour is similar for both sole species, with males swimming underneath a female towards the surface with synchronized movements. Spawning takes place after dusk preferably between 15 ºC and 21 ºC. Temperature and not photoperiod is the crucial factor in gonadal development (García-López *et al*., 2006). Temperature may also be involved in sex differentiation, as the daily thermo-cycles can determine sex ratios during larval development. This has an important economic implication since female sole grow faster than the male (Blanco-Vives *et al*., 2011). It is as well possible to control spawning season for both sole species, thus producing juveniles throughout the year. While wild-caught sole of both species will spawn in tanks or basins in captivity and produce eggs of high quality, this does not happen with sole produced in captivity. The missing factor seems to be related to the F_1 males, since F_1 females might mate successfully with wild-caught males. Future progress with male rearing could help solve the problem.

A crucial step in the rearing of an aquaculture species is the ability to control maturation and, ultimately, spawning. Maturation of F_1 Senegalese sole females has been successfully induced through hormonal manipulation and a detailed protocol for stripping of high quality eggs from Senegal sole females has been developed (Rasines *et al*., 2012; Rasines, 2013). Fertilization is based on frozen sperm from F_1 males. Thus the cycle has been closed and genetic programmes have been initiated to domesticate sole based on cultured generations for future selection of breeders to achieve improvement in culture yields.

3.1.2. Hatchery and nursery

Good quality sole eggs will typically have more than 80 percent hatching of fertilized eggs and more than 80 percent survival to settlement at the bottom at a size of 8 mm. Incubation of Senegalese sole eggs lasts for approximately 42 hours between 18 ºC and 20 ºC, with slight aeration and water renewal until hatching. Light-dark photoperiods are essential for the correct hatching and development of eggs and larvae. Light-dark cycles using blue light illumination maximize hatching rate (>90 percent), growth and development speed. Newly hatched larvae at a size of about 3 mm are stocked at 30 to 100 individuals per litre and reared in cylindro-conical tanks at a temperature ranging between 18–21 ºC and at salinities between 33–35‰. Larval rearing using green water technology is common (Conceição *et al*., 2007).

Senegalese sole larvae suffer a radical metamorphosis during the first 20–30 days after hatching (DAH), involving the migration of the left eye and the transition from a pelagic life to settlement at the tank surface, wall or bottom. Subsequently the post-larvae are transferred to nursery tanks and stocked at 3 000 individuals/m^2 under 12D:12L photoperiods at illumination intensities lower than 400 lx. Feeding takes place 2–4 times a day during light hours. At 40 DAH, larvae measure 16±0.8 mm. growth rates of larvae and post-larvae vary greatly depending on culture conditions. The growth potential of Sengalese sole is illustrated by sole stocked as un-weaned juveniles which may reach more than 400 g in earth ponds after one year. In tank farming you need another year to achieve that size, even at optimal temperature for growth.

An important problem that faces larval rearing based on *Artemia* is the occurrence of deformities and pigmentation abnormalities that are observable in varying degrees in many facilities. Most commercial farms have to expel from production as much as 50 percent of the nursery fish due to these defects (Gavaia *et al*., 2002). When fed natural zooplankton, these problems otherwise observed when feeding with *Artemia* and rotifer will not occur. Thus the metamorphosed sole will have no deformaties, normal pigmentation of the skin, normal eye movement during metamorphosis, easy weaning to formulated diet and no stress-related mortality when moved from hatchery to nursery.

Nutritional requirements for sole larvae are still poorly known, and one expects future progress to reduce the proportion of juveniles to be sacrificed (Conceição *et al*., 2007). One element is that the requirements of DHA in Senegalese sole are low compared to other pelagic larvae; this may be related to a predominance of EPA instead of DHA in the benthic fauna that constitutes settled larvae food items in the wild (Villalta *et al*., 2005). Co-feeding - that involves offering growing amounts of inert feed together with live prey at some point of the larval rearing – has also been shown to improve the quality of post-larvae when transferred to the nursery (Gamboa-Delgado *et al*., 2011).

3.1.3. On-growing

On-growing of sole is carried out with two major strategies: the use of earth ponds in the southern part of the Kingdom of Spain and the Portuguese Republic and tank farming (Dinis *et al*., 1999). However, the new enterprises are all based on tank farming and with use of stacked shallow raceways in racks with 4 or more levels.

3.1.3.1 Environmental conditions

The optimal rearing temperature of Senegalese sole is considered to be at around 20 ºC all considered, although better growth can be achieved at higher temperature, but with increased risk of disease outbreak (Costas *et al*., 2011). Common sole may be kept at 1–2 ºC lower temperature. With use of RAS, these temperatures can be kept on a yearly basis.

Sole species are euryhaline and can thus be farmed within a wide range of salinities from 10‰ to 38‰ (Salas-Leiton *et al*., 2008). Both species have a clearly nocturnal activity pattern, with locomotor activity peaking in the first part of the dark period, and progressively decreasing during the night. In fully controlled farming conditions the sole species can be offered night conditions during daytime to facilitate the farming routines, either as photoperiods of 12L:12D or simulations of the natural photoperiod, but with low-intensity blue light during day-time (Valente *et al*., 2011). Adjusting feeding schedules to the nocturnal rhythm requirements of sole may improve growth in culture and the fish may show better specific growth rate (SGR) and feed conversion ratio (FCR) and may have lower stress level. Senegalese sole displays clearly nocturnal self-feeding patterns under farming conditions, with about 80 percent of feed demands occurring at night. Therefore, feeding during daytime could be incompatible with the natural feeding rhythm of sole species (Boluda Navarro *et al*., 2009).

3.1.3.2. Nutrition

Soles display nocturnal feeding habits, and thus rely heavily on olfaction and other chemotactic stimuli for food-search behaviour. When whole homogenates of polychaetes are added to commercial feeds, the food search activity will increase. Polychaete homogenates and squid meal added to the feed are acting as attractants or improving feed palatability in both Senegalese and common soles. This indicates that both sole species need specially designed pellets to increase food intake and thus achieve a higher SGR (Branco *et al*., 2010; Silva *et al*., 2010). It has also been shown that sole species should have a lower level of crude fat than other farmed species, with a recommended level being 8–10 percent. This is another reason for a specially designed sole diet (Borges *et al*., 2009).

As a carnivorous species, sole needs a high percentage of protein in its diet and the recommended level is above 50 percent with 55 percent crude protein as an optimal level. Combining adequate plant protein sources with the inclusion of palatability-enhancing feed ingredients, such as squid meal or fish protein hydrolysate has been proved to be effective in Senegalese sole in terms of growth, survival and feed intake (Rema *et al*., 2008, Norambuena, 2012).

It has also been demonstrated that fish meal can be replaced by plant-source protein without any negative effect on growth, provided that dietary amino acids are balanced, adding crystalline indispensable amino acids when necessary and improving feed palatability with squid meal. Substitution of fish meal by plant protein does not have major effects on lipid content, fatty acid profile and volatile compounds composition of the sole's muscle.

3.1.3.3. Growth

The female has a higher growth rate than the male for both sole species (Imsland *et al*., 2004). Thus actions should be taken during larval rearing to achieve a far higher rate of females than males. With standard procedure the opposite has been observed for both species with 80 percent males and only 20 percent females. Females will typically reach about 400 g after 24 months while males should be harvested at less than 200 g (Valente *et al*., 2011).

It is important not to undertake abrupt increases in fish density since the fish may stop feeding for months, while a gradual increase in fish density has no negative impact. Stocking of tanks should thus be below 100 percent of bottom cover while subsequently the density may pass 200 percent bottom cover – or more than two layers of sole.

3.1.3.4. Stocking density

Stocking density has been demonstrated as a crucial variable of the growth performance of cultured fish. In soleid fish contradictory results on how density affects growth have been given by different authors. Significant effects of density on growth have been found for common sole stocked at six densities between one kg and 13 kg/m^2 for 55 days. SGR decreased with increasing stocking density (Schram *et al*., 2006).

In contrast, for Senegalese sole at four stocking densities between 2 kg and 30 kg/m^2 during 60 days, no significant differences in biomass production or growth rates were observed, concluding that Senegalese sole is compatible with high densities under intensive culture

(Salas-Leiton *et al*., 2008). However, higher plasma cortisol levels have been found and less free amino acids (FAA) in fish held at higher densities, indicating higher stress levels, accompanied by higher occurrence of pathologies. Stocking soles at high density (30 kg/m^2) increased stress 45-fold compared with fish stocked at low density, as shown by higher cortisol levels and by lower expression of some immune response-associated genes, but it did not affect growth. In fact, handling or induced stress did not affect growth of juvenile soles, although stressed fish showed higher levels of cortisol, plasma glucose and lactate levels (Salas-Leiton *et al*., 2010).

3.1.3.5. Size variability

Large size variation is an important issue in the farming of both sole species. Size variation in sole usually increases with time, leading to higher differences between fast and slow growers. Apparently, Senegalese sole does not show aggressive behaviour under culture conditions and larger-sized individuals do not monopolize the food source when stocked in ungraded conditions, where smaller fish usually access feed earlier (Salas-Leiton *et al*., 2010).

All populations tended to reach the same size variation regardless of whether or not they were graded. It seems group heterogeneity improves overall growth in sole, probably associated with more efficient social arrangements. This may suggest that there is a strong social effect behind growth of soles under culture conditions (Salas-Leiton *et al*., 2011).

3.1.4. Expected future improvements in sole farming

The genetic selection programme may within a few generations improve performance of Senegal sole in culture. These improvements may include higher growth rates at all stages, less stress of fish at high farming density due to domestication, a far smaller part of the population experiencing stunted growth as a result of selection for fast growth, almost exclusive farming of females that grow faster due to improvements of larval rearing methods, perfect pigmentation and no deformities in post-larvae, no stress-related mortality during transfer from hatchery to nursery and no need for grading of fish during culture.

3.2. COST OF PRODUCTION

In this section, we will analyse a farm with an annual production capacity of 350 tonnes. The technology used is that of shallow raceways (Øiestad, 1999) which has proved cost-effective e.g. in turbot farming (Bjørndal and Øiestad, 2010). Kamstra *et al.* (2001) say this technology is “very relevant” for sole species.

The current production of farmed sole is very small and with only a few active farms in business. Moreover, technologies in use differ from what is analysed in this report. Accordingly, knowledge about important variables and parameters such as growth and mortality is limited. Also, the market for juveniles is very “thin” which means it is impossible to observe market prices.

Assumptions about economic and biological parameters are based on information from project partners, Garcia Garcia and Garcia Garcia (2006), Kamstra *et al.* (2001) and meetings with farm representatives and other industry sources. The methodology is based on Asche and Bjørndal (2011). A number of sensitivity analyses will be undertaken.

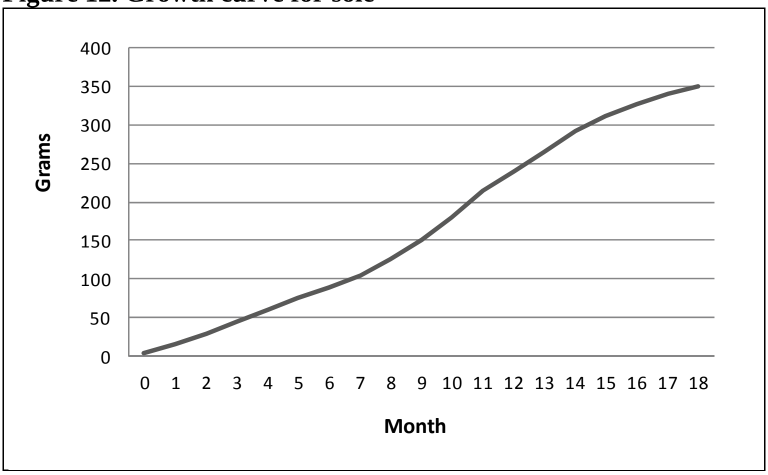
We start by presenting the production plan. Details regarding the growth curve, biomass growth, feeding and feed costs are given in the Appendix, Table A14.

3.2.1. Production plan

Fish size:	from 5 g to 350 g
Production period:	Release of 5 g juveniles in month 0, with harvest in month 18.

The growth curve is illustrated in Figure 12.

Figure 12. Growth curve for sole



<u>Production Costs and Outputs</u>

No of fry released, month 0	1.1 million
Mortality:	1% months zero and one, subsequently about 0.5% per month; 1 000 000 fish harvested in month 18. This gives a total mortality of 9.1% over the lifecycle.
Annual production:	350 tonnes
Feed conversion ratio:	1.1

Variable costs

Feed cost per kg	EUR1.40
Cost per juvenile	EUR 1.20
Number of workers	8
Wage cost per worker	EUR20 000/year
Electricity, gas, water and other operating costs	EUR 400 000/year
Maintenance	2% of total investment (excluding land)
Interest on working capital	10%
Insurance cost (fish stock)	3% of value of standing stock in any given year

3.2.2. Investments

As noted above, we will assume that the technology selected is that of raceways, as further developed in this project. Farm investments are given in Table 1. Land is estimated at EUR 200 000, buildings at EUR 1 850 000 with equipment and machinery at EUR 2 400 000. This gives total investment of EUR 4 550 000 or EUR 12.60 per kg production capacity for an annual output of 350 tonnes.

For the estimation of the annual interest and depreciation charge, the lifespan (amortization period) of the building is set at 20 years, while equipment and machinery are supposed to have an average lifespan of 17 years. The interest rate is set at 7 percent. The interest rate should be based on what investors in the industry require in terms of return on their investments as well as the riskiness of the project. On this basis, the assumption about interest rate appears reasonable. The interest rate on working capital was set at 10 percent. Working capital is often financed out of a line of credit. It is therefore natural that the interest rate will be higher than for long term investments.

The annual interest and depreciation charge is calculated according to the annuity principle, so that the annual charge is constant over time. In a sense, this corresponds to renting the land and leasing the building and capital equipment. Annual fixed costs amount to EUR 434 400.

Table 1. Farm investment

Investment	**Amount EUR**	**Amortization period**	**Annual interest and depreciation charge[b)] EUR**
Land	200 000	None	14 000
Building	1 850 000	20 years	174 600
Equipment and machinery	2 400 000	17 years[a)]	245 800
Total	4 550 000	-	434 400
Investment per kg production capacity	12.60	-	

a) Raceways etc., representing 80 percent of investment cost, have a lifespan of 20 years. The remaining 20 percent (pumps and electrical equipment) have a lifespan of five years. This gives an average amortization period of 17 years.

b) The annuity factor with 7 percent interest over 17 years is 0.10243; over 20 years it is 0.09439.

EU-investment grants may amount to 60 percent of building, equipment and machinery. This has been disregarded for now but will be considered later as part of the sensitivity analyses.

Other fixed costs:

Management	1 manager
Management cost per year	EUR 75 000 (including salary for manager)
Facility insurance	0.5% of value of initial investments in building, equipment and machinery

With this background, we proceed with analysis of cost of production of what we consider the “base case”.

3.2.3. Cost of production

To analyse cost of production, a *steady state* situation is assumed, i.e., the farm is fully operational. A farm may release several batches of juveniles in a year so as to have harvestable fish throughout the year. Provided the pattern of releasing and harvesting fish remains unchanged over time, the total amount harvested in one calendar year will be the same as the harvest from one year class (Asche and Bjørndal, 2011). For this reason, we can base the analysis on consideration of one year class.

It may take several years to develop a sole farm until it reaches full production. Cash flow planning is essential for this process (Asche and Bjørndal, 2011); however, the focus of attention for this analysis is a fully operational plan.

Table 2 gives annual costs as well as average cost per kg. Interest on working capital is included as a variable cost. This is because of the long production period for sole; throughout this period capital is tied down in the production process. In addition to cost of juveniles, working capital consists of feed, operating, labour, maintenance and management costs. While cost of juveniles is incurred throughout the period, other costs are for simplicity assumed to be incurred in a linear fashion over the 18 month production period.

Insurance cost for fish is set at 3 percent of the value of the standing stock in any given year which is set as equal to the cost of juveniles and average feed costs.

Table 2. Annual costs and average cost

Cost category	Annual costs (EUR)	Average cost EUR /kg
Variable:		
- Juveniles	1 320 000	3.77
- Feed	530 500	1.52
- Operating	400 000	1.14
- Labour	160 000	0.46
- Maintenance	85 000	0.24
- Interest on working capital	291 800	0.83
- Insurance	47 600	0.14
Sum of variable costs	2 834 900	8.10
Fixed costs:		
- Interest and depreciation on investments	434 400	1.24
- Management	75 000	0.21
- Insurance, building and equipment	21 250	0.06
Sum fixed costs	530 650	1.52
Total cost	**3 365 550**	**9.62**

Total annual costs amount to EUR 3 365 550, of which variable costs represents 84 percent and fixed costs 16 percent. Average cost of production is EUR 9.62/kg. Cost of production is largely driven by juvenile costs which are EUR 3.77/kg or slightly more than 39 percent of cost of production. A lower juvenile cost will also reduce interest on working capital and insurance. Feed is the second most important cost component with EUR 1.52/kg or 15.8 percent of cost of production. Operating, labour and maintenance costs combined amount to EUR 1.84/kg or 19.1 percent of cost of production. Interest on working capital, with EUR 0.83/kg or 8.6 percent of cost of production, is fairly substantial. This is a reflection of the long production period in which capital is tied down in fish. Interest and depreciation on investments are EUR 1.24/kg or 12.9 percent of cost of production. This is a fairly small share of cost of production, indicating limited economies of scale. This is due to the ability to add more raceways at a limited investment cost.

For comparison, in salmon aquaculture, the cost share of juveniles (smolts) is 12 percent, feed 54 percent, while financial cost and depreciation represent 10 percent (Asche and Bjørndal, 2011). The main trends in cost of production for farmed salmon is that, over time, the juvenile cost has come down, both in absolute and relative terms due to better quality of juveniles giving improved growth and reduced mortalities. Similarly, the cost share of interest and depreciation has come down due to increased production and improved efficiency. The cost share of feed, on the other hand, has increased substantially. The feed quality has improved, while the feed conversion ratio has decreased.

While the technology in salmon farming is different from that of sole, we would nevertheless expect to witness similar qualitative trends over time as the farming of sole expands.

3.2.4. Sensitivity analyses

As noted in the introduction, due to the limited production of sole, there is uncertainty about many variables and parameters. For this reason sensitivity analyses will be undertaken for different values of important parameters. The results will be compared with what we have called the base case, as presented above. In most instances, only one parameter will be changed so that the importance of a particular parameter on cost of production will be highlighted. Results from the sensitivity analyses are presented in Table 3.

As mentioned, EU grants may be available for investments in the aquaculture industry. This could represent an important incentive for new entry to this industry. We will here assume the maximum 60 percent grant is achieved for investments in building, equipment and machinery. Accordingly annual interest and depreciation charges will be reduced, and cost of production declines to EUR 8.90/kg, a 7.4 percent reduction compared to the base case.

Juveniles represent the largest cost share. We will consider the case where the cost per juvenile is reduced to EUR 0.90, a 25 percent reduction compared to the base case. This leads to a reduction in average cost of production to EUR 8.50/kg, an 11.6 percent reduction. Juveniles now represent 33 percent of the cost of production as compared to 39 percent in the base case. This reduction is due not only to lower juvenile costs, but also to reduced working capital and interest on standing stock.

Table 3. Sensitivity analyses: cost of production for various alternatives

	Average cost (EUR /kg)	Change compared to base case (%)
Base case	9.62	-
60% EU investment grant	8.9	-7.4
Cost per juvenile = €0.90	8.5	-11.6
Feed cost = €1.26/kg	9.36	-2.8
Annual operational costs = €600 000	10.23	+6.3
60% inv. grant, juvenile cost = €0.90, feed cost = €1.26/kg, annual operational cost = €600 000	8.16	-15.2
60% inv. grant, juvenile cost = €0.90, feed cost = €1.26/kg	7.53	-21.7

We also consider the case of a 10 percent reduction in the feed cost to EUR 1.26/kg. This gives rise to a cost of production of EUR 9.36/kg, a 2.8 percent reduction. In addition to lower feed costs, this case involves slightly lower working capital and interest on standing stock. A 10 percent reduction in the feed conversation ratio would give exactly the same result.

Operating, labour and maintenance costs are important variable costs of production. As the technology is still fairly new, we will consider the case of higher variable costs. This could also be due, for example, to an increase in energy costs. Specifically, we will consider a 50 percent increase in annual operating costs to EUR 600 000. This gives rise to a cost of production of EUR 10.23/kg, a 6.3 percent increase compared to the base case. In addition to increased operating costs, interest on working capital also increases.

Next we will consider two scenarios that involve simultaneous change in several parameters. First will be the combination of all the changes that have been considered, namely a 60 percent investment grant, a juvenile cost of EUR 0.90 and a feed cost of EUR 1.20/kg while annual operating costs are set at EUR 600 000. With all these changes, the cost of production becomes EUR 8.16/kg, a 15.2 percent decrease compared to the base case. Second, we consider a 60 percent investment grant, a juvenile cost of EUR 0.90 and a feed cost of EUR 1.20/kg (thus annual operating costs are set at EUR 400 000). In this case, the cost of production becomes EUR 7.53/kg, a 21.7 percent reduction compared to the base case. In this case, juveniles represent 37.6 percent of cost of production, as compared to more than 39 percent in the base case.

Juveniles represent the largest cost share with more than 39 percent in the base case, and a reduction in their price will be important for a reduction in the cost of production. As for the other parameters considered, there is limited sensitivity to the change in individual parameters. On the other hand, the combined effect of changes in several parameters on cost of production can be quite substantial.

3.2.5. Other studies

Only few studies on cost of production in sole farming are available and most of them are somewhat dated. Moreover, most are for other technologies than raceways. For these reasons, they are not directly comparable with the current analysis. Nevertheless, we will present some results from previous studies.

Kamstra *et al.* (2001) used a bioeconomic model to analyse farming of *S. senegalensis* in a recirculation system. A case study was performed for a farm producing 50 tonnes/year, where an average fish needs 17 months to grow from 5 g to 300 g. Productivity was fairly low with 35 kg/m^2/year. Average cost of production was EUR 7.59/kg. Adjusting for 34 percent inflation from 2000 to June 2014[9], this would correspond to EUR 10.18/kg in 2014, somewhat higher than in our base case.

As for individual costs, fingerlings – based on release of 5 g juveniles - represent EUR 1.42/kg, which is considerably less than in this study. Feed represents EUR 1.36/kg, operating costs (electricity, oxygen, gas, water) amount to EUR 1.15/kg and capital costs (interest and depreciation) amount to EUR 1.53/kg. In particular the low juvenile cost represents a very optimistic assumption. With the same assumption about juvenile costs as in our analysis, cost of production would have been considerably higher.

García García and García García (2006) point out that sole aquaculture has attracted great interest in recent years, both at the research and commercial level. This is particularly true

[9] It is not evident which price index should be used to correct for inflation. For simplicity, the Consumer Price Index (CPI), which increased from 87.06 as average for 2000 to 116.76 in June 2014, is used. See: http://statline.cbs.nl/StatWeb/publication/?DM=SLEN&PA=71099eng&D1=a&D2=64,77,90,103,116,129,142,155,168,181,194,200-239&LA=EN&HDR=T&STB=G1&VW=T

in Spain and Portugal since the species' rapid growth and high price provide a tremendous commercial opportunity.

García García and García García (2006) analyse the development of a land based farm with tanks for the farming of *S. senegalensis.* The production is based on the release of 5 g juveniles which are harvested when they reach 400 g. Four alternative farm sizes are considered with an annual output of 100, 200, 300 and 400 tonnes, respectively. Investment costs, excluding land, vary between EUR 2.15 million (100 tonne capacity) and EUR 3.37 million (400 tonne capacity). This implies somewhat lower investments than in our case (Table 2), mainly due to the use of a different technology.

In their study, the feed conversation rate is set at 1.2, slightly higher than in the current study. The feed price[10] is set at EUR 1.24/kg. With a 90 percent survival rate, which is close to what we have assumed, feed cost becomes EUR 1.90/kg - somewhat higher than in our case. The share of feed in total cost varies between 19 percent (100 tonne farm) and 24 percent (400 tonne farm) which is higher than in our analysis (15.8 percent). The price of 5–10 g juveniles was set at EUR 0.83/unit. Once more with a 90 percent survival rate, the juvenile cost becomes EUR 2.78/kg, lower than in our analysis. The share of juveniles in total cost varies between 30 percent (100 tonne farm) and 40 percent (400 tonne farm) while it is 39 percent in our base case. It must be borne in mind that in García García and García García (2006) the harvest weight of sole is 400 g as compared to 350 g in our analysis.

Average cost is EUR 8.43/kg for the 300 tonne farm as compared to EUR 8.24/kg for the 400 tonne form, indicating limited economies of scale. When correcting for 21 percent inflation from 2005 to May 2014[11], this becomes EUR 10.20/kg for the 300 tonne farm and EUR 9.97/kg for the 400 tonne farm which is somewhat higher than in our base case.

Howell *et al.* (2009), providing an overview over the status of sole farming in Europe while not presenting a cost analysis as such, state that juvenile production is based on orders only. Thus, there is no ordinary market for juveniles and market prices are not easily available. They quote a juvenile price of EUR 1.00 for a 5 g fish, which is slightly less than in this study. Also, Howell *et al.* (2009) note that juveniles represent up to 30 percent of production costs, again lower than in the base case.

Overall, while the studies represented are somewhat dated, and generally based on different technologies than in our case, they nevertheless give credence to the results forthcoming from our analysis.

3.2.6. Analysis

According to Schram *et al*. (2006), Dover sole (*Solea solea*) is a relatively slow growing species and demands relatively low stocking density. As a result optimization of production

[10] In García García and García García (2006), this price and the price of juveniles is given inclusive of VAT. Here, the prices have been corrected for VAT, which is appropriate, assuming a 21 percent VAT rate.
[11] In the Kingdom of Spain, the average CPI for 2005 was 86.209, while in May 2014 it was 104.299. Source: INE, National CPI base 2011. http://www.ine.es/jaxiT3/Tabla.htm?t=2559.

is important to sustain economic feasibility of farmed sole in land based systems. These considerations also apply to *Solea senegalensis.*

Howell *et al.* (2009) state that when quality issues relating to juveniles are resolved and demand – and thus production - increases, cost of production is likely to come down. Hatchery production is still at a very low level, and there are certain issues to be overcome in terms of weaning and feeding. Over time these will be reduced so that mortality will be reduced. Consequently, cost of production will decline.

The high cost of juveniles is due to the state of domestication of the species and the current scale of operations. With greater domestication, reproduction will improve. Moreover, the scale of production must be increased so as to reduce unit cost of production. Thus, the juvenile cost will come down over time.

On-growing is also still at a very low level. With more experience, the feed conversion ratio is likely to come down. The feed conversion ratio must be reduced to a level closer to one. This can be achieved with improvements in efficiency. Moreover, with larger production, the feed price will come down. Better and more specialised feed will be produced so that the quality of feed is likely to improve as has been the case for other farmed species (Asche and Bjørndal, 2011).

Thus, there are several reasons why cost of production is likely to come down as production expands. Moreover, the technology used does involve certain economies of scale. In a raceway system, as production capacity is increased, this will reduce investment cost per kg production capacity and reduce capital costs (interest and depreciation) per kg produced. Similarly, management cost per unit produced will come down. Overall, for the case of sole aquaculture, the most important factor is that juvenile costs are likely to come down. This will take place through larger hatchery production with improved quality of juveniles. As production is expanded, and more firms enter the hatchery sector, cost of production will come down.

In sum, cost of production can be expected to come down, as the industry expands. This reduction in cost of production that is possible with the farming technology under consideration is likely to be quite substantial and will be very important for the future development of the industry.

4. PRICE AND MARKET DEVELOPMENT FOR SOLE

4.1. MARKETS FOR SOLE

As shown in section one, almost all sole marketed is wild (about 98 percent). As noted, there are two types of sole. S. *solea*, or Dover sole, may be preferred in northern European countries while S. *senegalensis* may be preferred in southern European countries. Having said that, the quality is quite similar, and the market may not be able to really distinguish between the two.

More than 75 percent of the sole landings come from the Atlantic Northeast (North Sea), while landings from the Mediterranean and Atlantic Eastern Central represent 17 percent and 7 percent, respectively (FAO, 2014). Landings show an overall declining trend over the period analysed, from 66 553 tonnes in 1994 to less than half in 2013 (31 377 tonnes). Almost all landings correspond to common sole, with only 60 tonnes of Senegalese sole recorded for 2012.

In 2012, total sole landings amounted to 32 086 tonnes. The five most important EU countries in terms of sole landings were the Kingdom of the Netherlands (9 085 tonnes), the French Republic (7 695 tonnes), the Kingdom of Belgium (3 055 tonnes), the Republic of Italy (2 081 tonnes) and the UK (1 988 tonnes). Sole landings from the Kingdom of Morocco and the Arab Republic of Egypt accounted for 2 271 and 2 063 tonnes, respectively (FAO, 2014).

When it comes to farmed production, production did not start to expand until 2007 to reach 349 tonnes in 2010; since then it has been fluctuating around 300 tonnes, achieving 343 tonnes in 2012. In 2012, the French Republic produced 200 tonnes of *Solea senegalesis.* In the Kingdom of Spain, in 2011 85 tonnes of *Solea senegalesis* and 65 tonnes of *Solea solea* were produced; in 2012 the production was 95 tonnes of Senegalese sole and no S. *solea* (FAO, 2014). Other farmed sole producers include the Portuguese Republic with minor quantities from the Republic of Italy and the Hellenic Republic. According to Howell *et al.* (2009), most farmed production is from on-shore tank systems, either shallow raceways or conventional tanks, often in conjunction with recirculation systems.

Sole is sold in different markets in actual or potential competition with numerous other whitefish including lemon sole, plaice, turbot, sea bass and bream, hake, monkfish and others. Lemon sole, plaice, hake and monkfish are only available as wild product. Sole, tubot, sea bass and sea bream, on the other hand, are available wild and farmed, although farmed quantities are limited for turbot and even more so for sole.

Landings of lemon sole (*Microstomus kitt*), which is a flatfish substitute for sole even if it does not belong to the *Solea* family, were 9 500 tonnes in 2012 in Europe, the lowest quantity observed (FAO, 2014). Main landings in 2012 were from the UK (2 846 tonnes), the Republic of Iceland (1 614 tonnes), the Kingdom of Denmark (1 451 tonnes) and the French Republic (1 065 tonnes). Spanish landings that were the largest in 2011 (2 206 tonnes), however, decreased abruptly to 189 tonnes in 2012 for reasons that are not known. Euopean plaice (*Pleuronectes platessa*) and turbot (*Psetta maxima*) are also flatfish species. European plaice landings were slightly more than 100 000 tonnes in 2012. The Kingdom of the Netherlands with 32 258 tonnes, the Kingdom of Denmark with 21 366 tonnes and the UK with 18 742 tonnes represented more than 72 percent of total plaice landings. Turbot landings were more than 5 800 tonnes in 2012, with 1 740 tonnes from the Kingdom of the Netherlands, 800 from the French Republic, 755 from the UK and 710 from the Kingdom of Denmark. Turbot farmed production is reported to be 77 100 tonnes in 2012, however of this 64 000 tonnes come from the People’s Republic of China, and it is uncertain if this production really belongs to *Psetta maxima*. Other producing countries in 2012 were the Kingdom of Spain with 7 750 tonnes and the Portuguese Republic 4 400 tonnes.

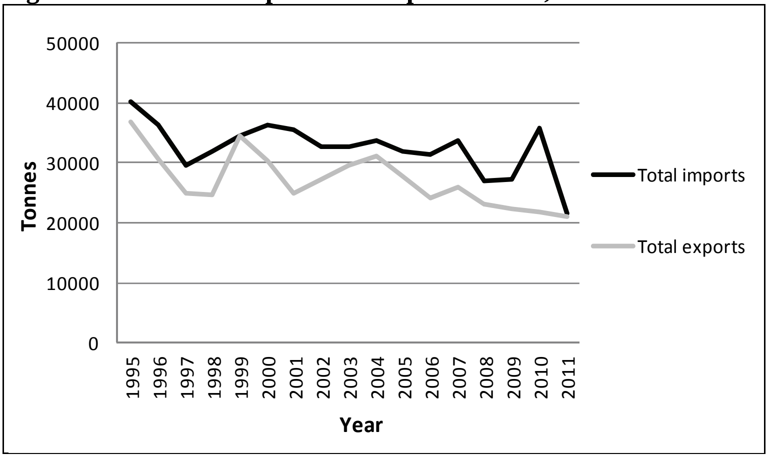
Between wild and farmed product, many consumers have a preference for wild, although this also depends on price and other attributes such as size and quality. Farmed fish may have a better appearance and look fresher than wild. Nevertheless, many consumers still prefer the wild variety. In addition, the various species are sold as fresh, chilled or frozen product. As an example, plaice is mostly sold frozen, although this is different for different species.

As noted above, most of the sole marketed is wild. Due to declining stock sizes, the average size of wild sole has been declining. Sole is sold to supermarkets and to the hotel, restaurant and catering (HORECA) sector. Restaurants naturally prefer larger sizes. HORECA want larger sized fish, generally 400–600 g. Fast growing fish can be selected for this purpose. As production expands, more of the sales are likely to go to supermarkets. This necessitates higher production volumes in order to meet the needs of large buyers. The small fish, on the other hand, will compete with wild product and fetch a lower price. A potential advantage of farming is that operators are able to provide a more stable supply over the year also in order to meet seasonal demand.

Although in the case study in section three we only considered an (average) fish size of 350 g, in reality farms will be able to produce fish of different sizes. As production expands, farmers will more and more be able to supply the fish sizes that are preferred by the market. In this way it is possible for producers to adapt to different market niches that require different sizes of fish. One may also differentiate between markets for luxury products and normal products. This may be according to size, as large fish typically fetch a substantially higher price per kg than small fish, but it could also be according to other quality attributes.

Total sole imports to the EU were about 40 000 tonnes in 1995, falling gradually to slightly less than 34 000 tonnes in 2007 (Figure 13). The subsequent years showed greater variability, with a peak of almost 36 000 in 2010, falling abruptly to less than 22 000 tonnes in 2011. In terms of product form, fresh or chilled imports are more important than frozen; for example, in 2011, fresh/chilled and frozen imports were 14 000 tonnes and 7 000 tonnes, respectively (Appendix, Table A15).

Figure 13. Total EU imports and exports of sole, 2000–2011



Source: FAO.

Exports peaked in 1995 with almost 37 000 tonnes (Appendix, Table A16). In recent years they have declined from 31 000 tonnes in 2004 to 21 000 tonnes in 2011. Exports of fresh or chilled product are more important than frozen ones. Since 2000, annual net imports have shown great variability, ranging from a minimum of 500 tonnes (2011) to a maximum of 14 000 tonnes (2010). Most of the trade is among EU countries, with net imports originating in Mediterranean countries not part of the EU.

In terms of the most important countries, in 2011, the top four countries – the Kingdom of the Netherlands, the French Republic, the Republic of Italy and the Kingdom of Spain – combined accounted for 90 percent of fresh/chilled imports, while in the same year the Kingdom of Spain and the Republic of Italy accounted for 95 percent of frozen imports (Appendix, Tables A17 and A18). On the export side, the Kingdom of the Netherlands, the French Republic, the Kingdom of Belgium, the UK and the Kingdom of Denmark accounted for 90 percent of fresh or chilled exports. In terms of frozen product, the Kingdom of the Netherlands alone accounted for 71 percent of exports (Appendix, Tables A20 and A21).

When we consider total sole supply, i.e., domestic production plus net imports, important markets for sole include the Kingdom of Spain, the French Republic, the Republic of Italy and the UK. Sole is mainly sold as an unprocessed product (i.e., whole fresh) in Mediterranean countries such as the Kingdom of Spain and the Portuguese Republic. In the Kingdom of Belgium, the French Republic and the UK there is also demand for processed products, in particular fillets. More detailed information is only available for the Kingdom of Spain.

Lemon sole imports are quite modest with 627 tonnes in 2010, down to 282 tonnes in 2011, all of which was frozen product. Frozen lemon sole exports were more than 400 tonnes in 2010 and 2011, which is small compared to common sole (see Tables A19 and A22 in the Appendix). Other relevant net imports of flatfish correspond to fresh/chilled megrim, frozen and frozen fillets of European plaice, fresh/chilled Greenland halibut and fresh/chilled and frozen Atlantic halibut.

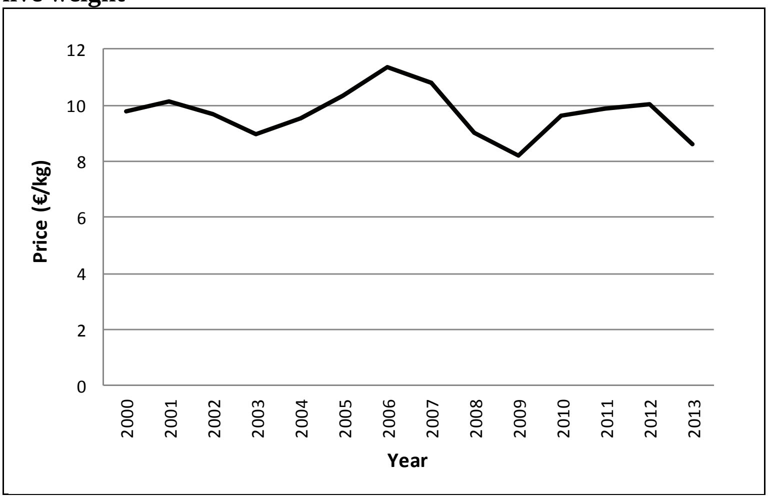
4.2. EX-VESSEL PRICES

In this section we will look at the development in prices over time. This will be done on the basis of prices from different sources.

For the UK, average annual ex-vessel prices are available from 2000 onwards (Appendix, Table A23). In recent years, the price increased from GBP 7.15/kg in 2008 to GBP 8.58/kg in 2011, presumably in response to a decline in harvest. However, in 2012 the price declined to GBP 8.12/kg with a further drop to GBP 7.30/kg in 2013.

When the prices are converted into Euros (Figure 14), there is less variation from year to year. The price peaked at EUR 11.35/kg in 2006, then felt to EUR 8.22/kg in 2009. For 2010–12 the price showed a slight upward trend, with EUR 10.12/kg recorded for 2012, however, falling to EUR 8.60/kg in 2013.

Figure 14. Average price of sole landed by UK vessels in the UK, 2000–2013, live weight

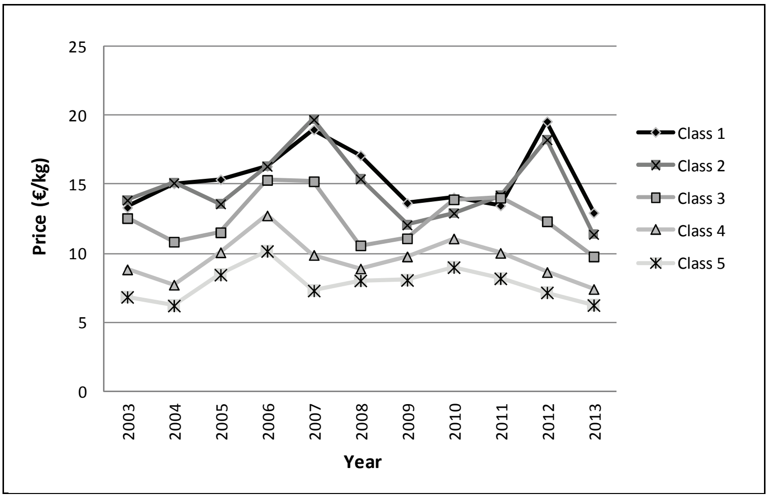


Source**:** Marine Management Organisation (2014).

As highlighted above, the Kingdom of the Netherlands has the highest catches of sole, in particular from Subarea IV. Ex-vessel prices are available from 2003 onwards. These are for five different size classes for the period 2003–2013, where 1 is the largest and 5 the smallest[12] (Figure 15 and Table A24 in the Appendix). There are substantial variations in prices over time, with price peaks in 2007 and 2012. Prices for the larger size classes (1 and 2) are substantially higher than for the lower weight classes (4 and 5). Nevertheless, qualitatively the trends over time on the whole are fairly similar for the different size classes. The peak in 2012 is believed to be in response to supply as the Dutch quota for the year was not fully used. Landings in 2013 increased substantially compared to 2012 due to increased stock size and probably improved fishing efficiency of the fleet.

[12] Size classes are defined as follows: 1: 38+ cm. 2: 33–38 cm. 3: 30–33 cm. 4: 27–30 cm. 5: 24–27 cm.

Figure 15. Ex-vessel sole prices by size class for the Kingdom of the Netherlands, 2003–2012



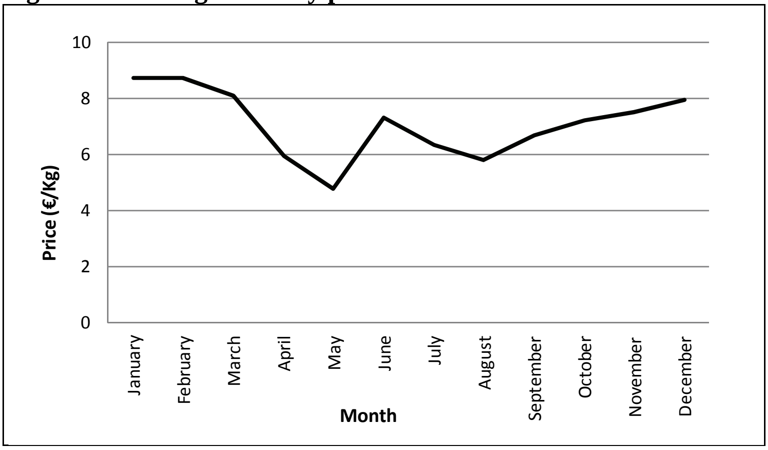
***Source*:** Wageningen UR database.

The Dutch prices are more volatile than those of the UK, presumably due to larger quantity variability over time. Comparison is also difficult, as there are five size classes for Dutch sole and only one for the UK. Nevertheless, the price trends over time appear similar for the two countries.

There is also substantial seasonal variation as shown by Rijnsdorf *et al.* (2012). This variation has mainly to do with spawning: during spawning, the fish use much of their reserves, and hence contain less meat. This results in prices being lower in the spawning season, especially for the larger size classes.

Average monthly prices for 2013 for the UK are given in Figure 16 and Table A25 in the Appendix. There is a marked seasonal variation in price. Price is at its highest in winter (November-March). It is at its lowest in May, the peak season for spawning, when the price is only 60 percent of the price for January.

Figure 16. Average monthly price for sole in 2013: UK vessels in UK ports



***Source*:** Marine Management Organisation (2014).

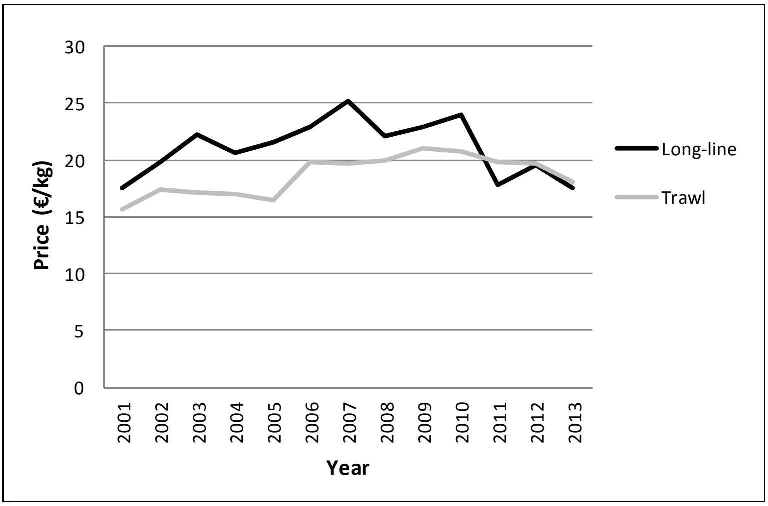
Average annual ex-vessel prices for wild sole by fishing technology (trawl and long-line) are available for Catalonia (Spanish Mediterranean) for 2000–2013 (Figure 17 and Table A26 in the Appendix). The overall average price in 2000 was EUR 13.11/kg, with an upward trend to just over EUR 19.60/kg in 2009–2010; subsequently declining, with EUR 16.51/kg observed for 2013. Prices of sole caught with long-line were significantly (12 percent) higher than the ones captured by trawlers at the beginning of the period. This price margin between sole captured by long-liners and trawlers could be explained by the larger size of the individuals captured by long-liners and the fish being less damaged by the gear. However, in recent years the price margin between the two gears has decreased.

The prices in Catalonia are substantially higher than those observed for the UK and also on the whole higher than those for the Kingdom of the Netherlands. This could be due to size and quality differences as well as market considerations.

Ex-vessel sole prices in Catalonia are also higher than the prices in Vigo (Galicia, Atlantic Spain), in part due to fresher products (vessels in Catalonia go to port every day to sell the fish) and also because overall prices are higher in Catalonia than Galicia.

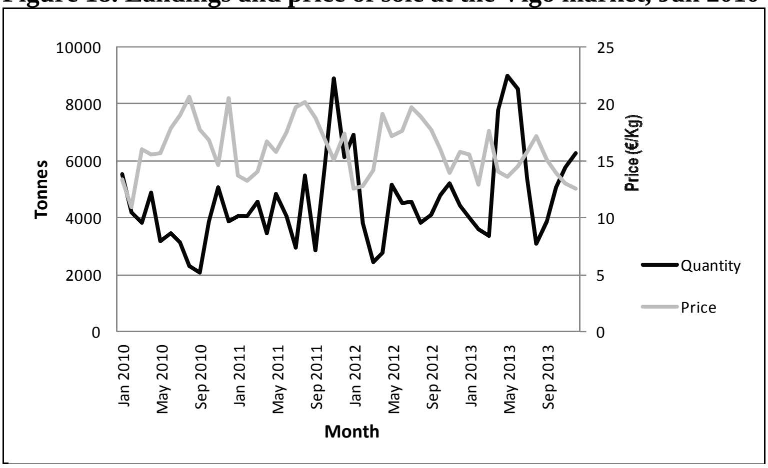
Monthly landings and price data for sole from January 2010 until December 2013 are available for Vigo (Figure 18 and Table A27 in the Appendix). Landings are seen to be fairly modest. It also appears there is an inverse relationship between price and quantity: as quantity increases, price declines. From these prices the existence of intra-annual variations (i.e., seasonality) can also be observed.

Figure 17. Average annual ex-vessel sole price by fishing gear in Catalonia, Spain, 2000–2013



Source**:** Guillen and Franquesa (2015).

Figure 18. Landings and price of sole at the Vigo market, Jan 2010–Dec 2013



Source: Xunta de Galicia (2014).

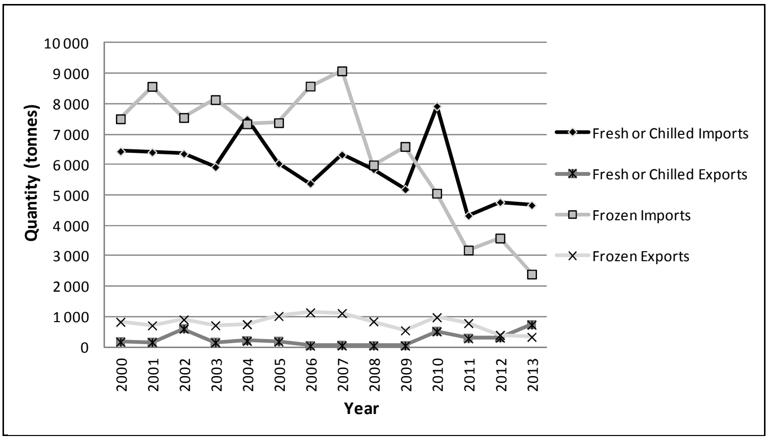
4.3. WHOLESALE MARKETS IN THE KINGDOM OF SPAIN

Domestic supply of sole in the Kingdom of Spain was 573 tonnes in 2011, down to 458 tonnes in 2013 (section two). Most of this was from capture, with farmed production of *S. senegalensis* being 85 tonnes in 2011, increasing to 95 tonnes in 2012, while the production of common sole which was 65 tonnes in 2011 was reduced to zero in 2012. Despite the rather limited domestic production, the Kingdom of Spain is one of the largest – if not the largest – market for sole in Europe. Due to the limited domestic supply most of the sole consumed is imported.

Annual imports (and exports) of fresh (or chilled) and frozen sole from 2000–2013 are given in Figure 19 (see Appendix, Tables A28 and A29). Frozen imports were 7 500 tonnes in 2000 and peaked at 9 100 tonnes in 2007. They subsequently declined to 2 400 tonnes in 2013. Imports of fresh/chilled sole varied around 7 000 tonnes annually up to 2010 but have declined in the last three years with 4 700 tonnes recorded in 2013. In 2000, total imports were 13 900 tonnes; by 2013, they were almost reduced by half to 7 100 tonnes.

Exports of fresh/chilled product are limited in most years but have shown an upward trend recently, with more than 700 tonnes recorded for 2013. Exports of frozen sole varied between 700 and 1 100 tonnes up to 2008 but have subsequently declined to just over 300 tonnes in 2013. Total sole exports stood at less than 1 100 tonnes in 2013. Thus exports are small compared with imports.

Figure 19. Quantity of fresh or chilled and frozen sole imports and exports, 2000–2013

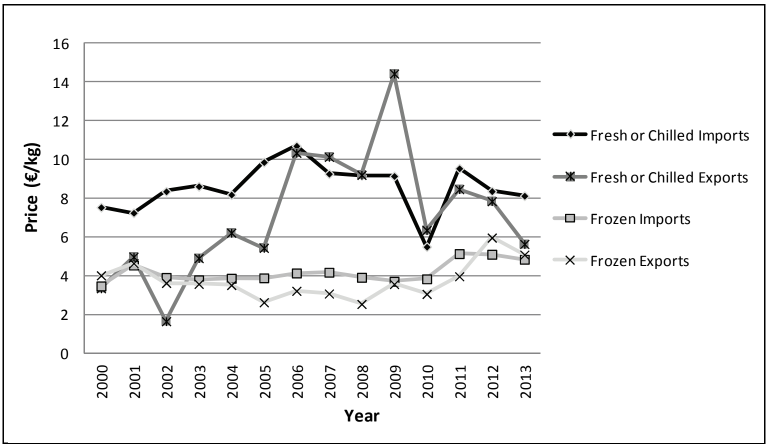


Source: Agencia Tributaria (2014).

Average import and export prices are given in Figure 20. The price of frozen imports was fairly stable around EUR 4.00/kg for most of the period but has been around EUR 5.00/kg during the last three years. The price of fresh/chilled imports is substantially higher than frozen, in most years more than EUR 8.00/kg, with EUR 8.13/kg in 2013.

The price of frozen exports is in most years less than that of frozen imports, suggesting lower quality product is re-exported, however, the price has increased in recent years to EUR 5.97/kg in 2012, down to EUR 5.09/kg in 2013. The price of fresh/chilled exports is seen to be highly variable; however, as noted above, quantity is in many years very small. In recent years, the trend has been similar to that of the import price.

Figure 20. Average price of fresh/chilled and frozen sole imports and exports, 2000–2013



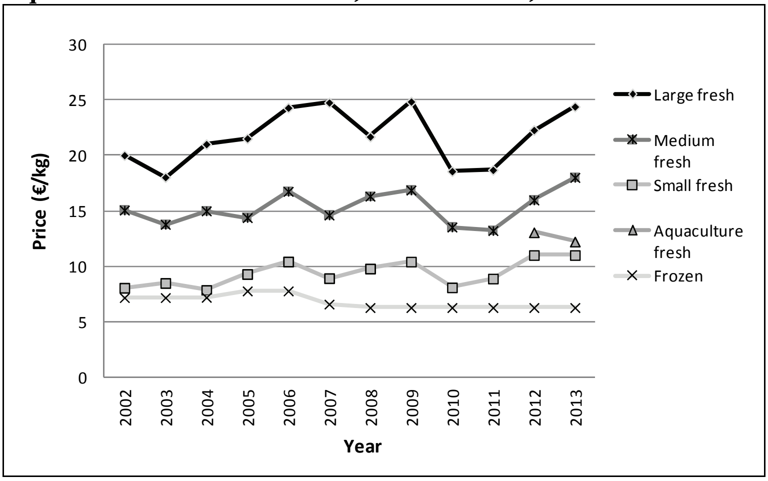
Source: Agencia Tributaria (2014).

Most sole is traded at the two major wholesale markets in Barcelona and Madrid. Sales of fresh sole at Barcelona's wholesale market, Mercabarna, were around 1 800 tonnes annually for the period 2006–2008 (Appendix, Table A30). Subsequently sales have declined, with 1 355 tonnes recorded in 2013. Frozen sales have shown a reduction from 287 tonnes in 2006 to 183 tonnes in 2013. This implies total quantity has been reduced from 2 069 tonnes in 2006 at a value of EUR 27.7 million to 1 538 tonnes in 2013 valued at EUR 15.4 million. The price of fresh sole has come done, in particular after 2010, to EUR 10.00/kg in 2013. The price of frozen sole is substantially less than that of fresh product; however, the difference appears to have become less over time.

A longer time period and more detailed data are available for Madrid's wholesale market, MercaMadrid (Appendix, Tables A31 to A33). Total quantity was 2 007 tonnes in 2002, showing a slight reduction to 1 974 tonnes in 2013 (including farmed product). Nominal value, however, increased from EUR 22.3 million in 2002 to EUR 24 million in 2013, indicating an increase in average nominal price.

For Madrid, information is available on the evolution of sales over time of big, medium and small fresh sole; that the development of frozen sole is different as well as their respective prices (Appendix, Table A33). As for quantity of large sole, this varies over time. For Madrid, price observations are also available for different sizes of wild fresh sole as well as farmed and frozen sole. This allows for a comparison between these prices (Figure 21). When it comes to prices, the price of large sole (over 1 kg) is higher than that of medium sized sole which is again higher than that of small sole (under 500 g). This is as expected. There is, however, a very substantial price difference: large sole often fetches a price that is twice the price of small sole. As for price trends, it is interesting to note that prices of large, medium and small fresh sole have all been increasing since 2010. This trend is different from that observed in Barcelona.

Figure 21. Average Price per Year: Sole, Large Fresh, Medium Fresh, Small Fresh, Aquaculture Fresh and Frozen, MercaMadrid, 2002–2013



Source: MercaMadrid (Appendix, Table A33).

When it comes to farmed sole, data are available for only two years. The price is slightly higher than that of small fresh sole, but less than that of medium sole. This may be a consequence of farmed sole being less than 500 g. It is also noticeable that even fresh small sole fetches a considerably higher price than that of frozen sole.

4.4. ANALYSIS

Guillen and Franquesa (2015) have analysed price evolution for several fish species in the Kingdom of Spain at the retail, wholesale and ex-vessel level (see Appendix, Figure A1, for illustrations for some of the species). When considering wild and farmed sea bream, sea bass and turbot prices at wholesale level in the Kingdom of Spain it is possible to see that wild prices were increasing until about 2008 and then started decreasing, similar to the other fish luxury products. On the other hand, over the same period farmed prices were relatively constant or decreasing and then started increasing similar to what may be considered for basic or normal products. This suggests it is possible that wild and farmed sole could have different price trends and thus belong to different markets, as appears to be the case for other fish products. The same could be true for large wild sole as compared to small and wild and for wild sole compared to farmed.

There are few market studies for sole. Nielsen, Smit and guillen (2009) undertook econometric studies of European whitefish markets including species such as sole, lemon sole, plaice, hake, monkfish and turbot. The authors use the term "benchmarking" to classify the relationship between different products, and the criterion they use to assess this is to study the interdependence between the prices of different products. This is done by comparing own and cross price elasticities. When it comes to hake and sole, they found a bidirectional relationship. In particular, hake quantity was found to affect the price of sole, however, because the hake price was more affected by the sole quantity than by its own quantity, sole was chosen as the benchmarking species. Based on the relationship that was found between sole and hake, the authors talk about a Southern European fish market as the largest hake consumption takes place in the Kingdom of Spain, the Republic of Italy, the

French Republic and the Portuguese Republic. One might believe that hake rather than sole should be the species benchmarking the whitefish market in Southern Europe or at least in the Kingdom of Spain as the hake market is so much larger than that for sole. One way to explain this possible divergence is that the analysis was done at a fairly aggregate level so that if it were undertaken at a more disaggregate level, results might have been different. For example, hake includes many different products that are aggregated: these include luxury and basic products that do not have the same price trends (see Asche and Guillen, 2013). Thus, in the case of hake there are products differentiated by quality and size that are not part of the same market. Fish products tend to have higher own price elasticities when they are considered luxury products as they have fewer substitutes. Nielsen, Smit and Guillen (2009) also found that sole affects the prices of hake, monkfish and lemon sole; however, no relationship was found between turbot and sole. This might be due to the existence of turbot aquaculture that could affect turbot prices and represents a topic for further investigation.

As illustrated for the Kingdom of Spain, wild sole is available as large, medium and small product with very different prices: in addition, frozen sole is available. Wild sole is believed to be part of the same market as the larger and fresher hakes which are considered luxury products, together with, for example, monkfish. Smaller hake and imported hake would be part of the same market as blue whiting and other whitefish which can be considered basic or normal products. A very important question is whether consumers can differentiate between wild and farmed sole by themselves, or the existing differences in prices are because of the current labelling regulation (that in the EU mandates stating the origin of all fish products) and consumers' personal perceptions (wherebyconsumers believe that wild products are better than farmed ones). As shown above, farmed sole appears to be more similar in size to small sole; also the price is more similar to small sole than that of large sole. This may suggest that sole might be in the second market, that of basic-normal products. It is a major challenge to farmed sole producers to develop products that might fit into the luxury category.

5. FUTURE DEVELOPMENTS

The development of commercial sole farming still faces many challenges. This relates both to the production and to the markets. On the one hand, efficiency in production must be achieved so as to reduce cost of production. On the other hand, new markets for farmed sole must be developed both in terms of supermarkets and the HORECA channel. It is, however, evident that the research capability relating to sole farming that has become established in the key problem areas will help overcome challenges faced by this industry.

According to Howell *et al.,* (2009), the industry has not grown as expected and several producers on the Mediterranean coast have been forced to close due to disease problems. However, after that time diseases have not been an issue. From a commercial perspective, Howell *et al.,* (2009) state that immediate priorities should focus on key issues limiting production and are seen to be as follows: improve egg and larval quality particularly with respect to hatchery reared stocks. This is very much supported by the cost analysis we have undertaken, where in the base case juveniles represent slightly more than 39 percent of cost of production. It is essential that this cost share be reduced over time.

According to Howell *et al.,* (2009), sole farming is still a marginal business with cost of production around EUR 8–9/kg before interest, administration and sales costs. Adding these costs would likely bring production cost up to more than EUR 10/kg, also when taking inflation into account. The minimum viable capacity for a production unit is more than 100 tonnes which is still not proving to be attractive to investors considering the risks involved. This, however, appears to have changed in recent years with development of new sole farms having a production capacity of around 2 000 tonnes.

The results of this study are more optimistic, very much due to the fact that a new farming technology is considered. In the base case, cost of production is EUR 9.62/kg while farmed sole price at the Madrid wholesale market in 2013 was EUR 12.25/kg. This currently gives a significant margin for farmed sole producers. The sensitivity analyses showed how cost of production would come down due to improved efficiency and reduced prices of input factors. In particular, with a 60 percent investment grant, a juvenile cost of EUR 0.90 and a feed cost of EUR 1.20/kg, the cost of production becomes EUR 7.53/kg, a 21.7 percent reduction compared to the base case. In this case, juveniles represent 37.6 percent of cost of production, as compared to more than 39 percent in the base case. This does not take into consideration economies of scale and reduction in operating and labour costs over time. The cost share of juveniles is extremely high and is likely to come down as the production of juveniles increases. It will also come down as a consequence of improved quality of juveniles, leading to higher growth and reduced mortality.

Overall, it is not unreasonable to expect that cost of production will be reduced towards EUR 7.00/kg over time. This production cost should allow farmed sole producers to obtain substantial financial benefits if the farmed sole price is not reduced by more than 40 percent based on the 2013 MercaMadrid price[13]. The economic advantages of the farming technology in question are thus very considerable.

[13] There are 23 wholesale markets in Spain, close to the main consumption areas. Most of these wholesale markets sell seafood products. Prices in wholesale markets follow similar trends over time and benchmark prices of other minor markets.

There are also challenges on the market side. In order to serve supermarkets, farms must be able to supply larger quantities than at present. An important issue is also that of fish size. Price observations show that large sole command a much higher price than small sole. Moreover, the HORECA channel in particular prefers sole of larger size than most of the current farm production. In addition, many consumers still prefer wild product to farmed. Thus, it is important that information campaigns on the quality and merits of farmed products continue to be disseminated.

There are, however, also advantages for farmers. As production expands, they will be able to provide consistent supply over the year, also in line with seasonal trends in consumer demand. This, of course, necessitates efficient logistics. Moreover, with improved control of the production process, fish size can also be adapted to market demand. In addition, farmers have control over many aspects of the quality of the product.

The economic advantages of the optimal farming technology that has been analysed are such that they should ensure current and future profitability of sole farming. As a consequence, the prospects for expansion in sole farming in the coming years are good.

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APPENDIX: DATA

CAPTURE PRODUCTION

Table A1. Sole: SSB and landings Subarea IV, 1990-2013 (tonnes)

Year	SSB	Landings
1990	89 322	35 120
1991	77 118	33 513
1992	76 988	29 341
1993	55 569	31 491
1994	73 978	33 002
1995	58 878	30 467
1996	38 505	22 651
1997	27 174	14 901
1998	20 061	20 868
1999	40 763	23 475
2000	37 777	22 641
2001	29 496	19 944
2002	30 546	16 945
2003	24 839	17 920
2004	36 909	18 757
2005	31 373	16 355
2006	23 585	12 594
2007	17 351	14 635
2008	34 528	14 071
2009	31 072	13 952
2010	30 201	12 603
2011	30 285	11 485
2012	42 309	11 610
2013	48 871	13 138

Source: ICES Advice, June 2014.

Table A2. Sole: official landings and ICES landings, Subarea IV (tonnes)

Year	Belgium	Denmark	France	Germany	Netherlands	United Kingdom (E/W/NI)	Other countries	Total reported	Unallocated landings	ICES Total	TAC
1990	2 389	1 427	352	2 296	18 202	1 614	263	26 543	8 577	35 120	25 000
1991	2 977	1 307	465	2 107	18 758	1 723	271	27 608	5 905	33 513	27 000
1992	2 058	1 359	548	1 880	18 601	1 281	277	26 004	3 337	29 341	25 000
1993	2 783	1 661	490	1 379	22 015	1 149	298	29 775	1 716	31 491	32 000
1994	2 935	1 804	499	1 744	22 874	1 137	298	31 291	1 711	33 002	32 000
1995	2 624	1 673	640	1 564	20 927	1 040	312	28 780	1 687	30 467	28 000
1996	2 555	1 018	535	670	15 344	848	229	21 199	1 452	22 651	23 000
1997	1 519	689	99	510	10 241	479	204	13 741	1 160	14 901	18 000
1998	1 844	520	510	782	15 198	549	339	19 742	1 126	20 868	19 100
1999	1 919	828		1 458	16 283	645	501	21 634	1 841	23 475	22 000
2000	1 806	1 069	362	1 280	15 273	600	539	20 929	1 603	22 532	22 000
2001	1 874	772	411	958	13 345	597	394	18 351	1 593	19 944	19 000
2002	1 437	644	266	759	12 120	451	292	15 969	976	16 945	16 000
2003	1 605	703	728	749	12 469	521	363	17 138	782	17 920	15 850
2004	1 477	808	655	949	12 860	535	544	17 828	-681	17 147	17 000
2005	1 374	831	676	756	10 917	667	357	15 579	776	16 355	18 600
2006	980	585	648	475	8 299	910		11 933	667	12 600	17 670
2007	955	413	401	458	10 365	1 203	5	13 800	835	14 635	15 000
2008	1 379	507	714	513	9 456	851	15	13 435	710	14 145	12 800
2009	1 353	NA	NA	555	12 038	951	1	NA	NA	13 952	14 000
2010	1 268	406	621	537	8 770	526	1.38	12 129	474	12 603	14 100
2011	857	346	539	327	8 133	786	2	10 990	495	11 485	14 100
2012	593	418	633	416	9 089	599	3	11 752	142	11 610	16 200
2013	697	497	680	561	9 987	867	0	13 291	-153	13 138	14 000

Source: ICES Advice, June 2014.

Table A3. Sole: SSB and landings Division IIIa and Subdivisions 22-24, 1990-2013 (tonnes)

Year	SSB	Landings
1990	2 626	1 050
1991	3 114	1 011
1992	3 880	1 294
1993	3 812	1 439
1994	3 733	1 198
1995	3 473	1 297
1996	2 968	1 059
1997	2 455	814
1998	1 719	605
1999	2 287	638
2000	2 175	646
2001	1 958	476
2002	2 611	862
2003	2 884	619
2004	3 046	824
2005	3 492	990
2006	2 935	836
2007	2 024	633
2008	1 634	655
2009	1 885	641
2010	1 615	538
2011	1 578	552
2012	1 441	358
2013	1 037	332

Source: ICES Advice, June 2014.

Table A4. Sole: official landings and ICES landings,Subarea IIIa and Subdivisions 22–24 (tonnes)

Year	Denmark	Sweden	Germany	Belgium	Netherlands	Norway	Working Group Corrections	Total
1990	592	29		2			427	1 050
1991	962	38	+				11	1 011
1992	1 228	54	12					1 294
1993	1 371	68	9				-9	1 439
1994	1 186	12	4				-4	1 198
1995	1 232	65	6				-6	1 297
1996	987	57	612				-597	1 059
1997	760	52	2					814
1998	512	90	3					605
1999	589	45	3					637
2000	732	34	11				-132	645
2001	556	25					-103	478
2002	555	15	11				281	862
2003	289	11	17				301	618
2004	398	16	18				392	824
2005	781	30	34				145	990
2006	742	38	43		4	9		836
2007	540	45	39		0	9		633
2008	576	34	35		3	7		655
2009	573	37	27			4		641
2010	459	46	26		3	3		538
2011	463	53	33			3		552
2012	322	30	0		0	6		358
2013	264	54	9		0	6		332

Source**:** ICES Advice, June 2014.

Table A5. Sole: SSB and landings, Division VIId, 1990–2013 (tonnes)

Year	SSB	Landings
1990	9 529	3 647
1991	8 716	4 351
1992	11 106	4 072
1993	13 055	4 299
1994	12 492	4 383
1995	11 029	4 420
1996	12 087	4 797
1997	10 455	4 764
1998	8 064	3 363
1999	8 968	4 135
2000	8 459	3 476
2001	7 545	4 025
2002	8 524	4 733
2003	10 365	5 038
2004	11 359	4 826
2005	11 382	4 383
2006	9 860	4 833
2007	10 391	5 166
2008	12 681	4 517
2009	11 530	5 266
2010	9 125	4 409
2011	10 554	4 133
2012	12 941	4 048
2013	13 370	4 390

***Source*:** ICES Advice, June 2014.

Table A6. Sole: official landings and ICES landings, Division VIId (tonnes)

Year	Belgium	France	United Kingdom (E+W)	Other countries	Total	Unallocated*	ICES total landings	TAC
1990	996	1 255	785	.	3 036	611	3 647	3 850
1991	904	2 054	826	.	3 784	567	4 351	3 850
1992	891	2 187	706	10	3 794	278	4 072	3 500
1993	917	2 322	610	13	3 862	437	4 299	3 200
1994	940	2 382	701	14	4 037	346	4 383	3 800
1995	817	2 248	669	9	3 743	677	4 420	3 800
1996	899	2 322	877	.	4 098	699	4 797	3 500
1997	1 306	1 702	933	.	3 941	823	4 764	5 230
1998	541	1 703	803	.	3 047	316	3 363	5 230
1999	880	2 251	769	.	3 900	235	4 135	4 700
2000	1 021	2 190	621	.	3 832	-356	3 476	4 100
2001	1 313	2 482	822	.	4 617	-592	4 025	4 600
2002	1 643	2 780	976	.	5 399	-666	4 733	5 200
2003	1 657	3 475	1 114	1	6 247	-1 209	5 038	5 400
2004	1 485	3 070	1 112	.	5 667	-841	4 826	5 900
2005	1 221	2 832	567	.	4 620	-236	4 384	5 700
2006	1 547	2 627	678	.	4 852	-18	4 834	5 720
2007	1 530	2 981	801	1	5 313	-147	5 166	6 220
2008	1 368	2 880	724	.	4 972	-455	4 517	6 593
2009	1 475	2 886	754	6	5 121	145	5 266	5 274
2010	1 294	2 407	674		4 374	35	4 409	4 219
2011	1 181	2 283	686		4 150	-17	4 133	4 852
2012	920	2 475	623	0.25	4 018	30	4 048	5 580
2013**	954	2 865	605		4 424	-34	4 390	5 900

* Unallocated mainly due to misreporting
** Landings in 2013 are preliminary.
***Source*:** ICES Advice, June 2014.

Table A7. Sole: SSB and landings, Division VIIe, 1990–2013 (tonnes)

Year	SSB	Landings
1990	3 013	1 306
1991	2 740	852
1992	2 632	896
1993	2 617	904
1994	2 887	800
1995	2 931	856
1996	2 811	833
1997	2 703	950
1998	2 730	880
1999	2 736	956
2000	2 764	912
2001	2 846	1 069
2002	3 026	1 105
2003	3 198	1 078
2004	3 025	1 074
2005	3 125	1 037
2006	2 705	1 016
2007	2 776	1 015
2008	2 590	908
2009	2 948	700
2010	3 365	698
2011	3 505	801
2012	3 710	872
2013	3 489	882

***Source*:** ICES Advice, June 2014.

Table A8. Sole: official landings and ICES landings, Division VIIe (tonnes)

Year	Belgium	France	Ireland	Jersey	Guernsey	United Kingdom (E, W & NI)	UK other	Unallocated	Total
1990	41	81		1	3	632		556	1 315
1991	35	325				477		15	852
1992	41	267			2	457	9	119	895
1993	59	236		1		479	18	111	904
1994	33	257				546		-38	800
1995	21	294		1	2	562		-24	856
1996	8	297				428		91	833
1997	13	348	1	13	13	470		91	949
1998	40	343		17	3	369		108	880
1999	13			18	3	375		548	957
2000	4	241		22	5	386		256	914
2001	19	224		20	5	382		419	1 069
2002	33	198		15	5	289		566	1 106
2003	1	363	1	15	5	235		458	1 078
2004	7	302		7	6	172		581	1 075
2005	26	406		17	5	505		80	1 039
2006	32	357		4	4	568	0	56	1 022
2007	34	384	2	2		525	4	64	1 015
2008	28	312	0	2	6	464		96	908
2009	17	386		1	3	374	3	-83	701
2010	17	375		2	3	361	2	-62	698
2011	22	401		2	4	422		-50	801
2012	39	325	0	1	2	504		1	872
2013*	29	321			4	532		-4	883

* Landings in 2013 are preliminary.

***Source*:** ICES Advice, June 2014.

Table A9. Sole: totals for combined North Sea and English Channel areas, 1990–2013 (tonnes)

Year	SSB	Landings
1990	104 490	41 123
1991	91 688	39 727
1992	94 606	35 603
1993	75 053	38 133
1994	93 090	39 383
1995	76 311	37 040
1996	56 371	29 340
1997	42 787	21 429
1998	32 574	25 716
1999	54 754	29 204
2000	51 175	27 675
2001	41 845	25 514
2002	44 707	23 645
2003	41 286	24 655
2004	54 339	25 481
2005	49 372	22 765
2006	39 085	19 279
2007	32 542	21 449
2008	51 433	20 151
2009	47 435	20 559
2010	44 306	18 248
2011	45 922	16 971
2012	60 401	16 888
2013	66 767	18 742

Source**:** ICES Advice, June 2014.

Table A10. Sole: total capture production by fishing area (tonnes)

Year	Atlantic, Northeast	Atlantic, Eastern Central	Mediterranean and Black Sea	Total
1990	41 572	3 674	9 429	54 675
1991	42 806	8 712	9 635	61 153
1992	42 586	12 502	9 685	64 773
1993	45 405	9 952	8 867	64 224
1994	48 052	10 047	8 454	66 553
1995	44 147	1 944	9 198	55 289
1996	34 460	1 617	6 949	43 026
1997	27 279	2 589	5 917	35 785
1998	31 293	7 411	5 047	43 751
1999	35 718	3 122	4 179	43 019
2000	34 728	6 283	5 169	46 180
2001	32 284	4 613	4 977	41 874
2002	29 586	3 873	5 548	39 007
2003	31 700	2 801	6 273	40 774
2004	31 294	2 966	5 340	39 600
2005	29 243	3 308	5 246	37 797
2006	25 463	3 723	6 403	35 589
2007	27 291	3 696	6 322	37 309
2008	24 966	3 351	5 795	34 112
2009	27 348	4 140	6 373	37 861
2010	25 286	3 386	6 286	34 958
2011	23 823	2 366	5 897	32 086
2012	23 802	2 223	5 352	31 377

***Source*:** FAO, 2014.

Table A11. Sole: total capture production (tonnes)

	Albania	Algeria	Belgium	Bulgaria	Channel Islands	Croatia	Denmark
Year / Species	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***
1990	...	350 F	5 230	-	3 F	...	2 033
1991	...	280 F	5 658	-	3 F	...	2 314
1992	...	320 F	4 509	-	2	...	2 722
1993	...	350 F	5 231	-	2 F	...	3 091
1994	...	400 F	5 703	-	2	...	3 073
1995	25	313	5 457	-	2 F	...	3 039
1996	27	387	5 150	-	9	...	2 083
1997	21	333	4 514	-	26	...	1 478
1998	35	285	4 102	-	21	...	1 050
1999	31	234	4 492	-	21	...	1 433
2000	41	278	4 479	-	26	...	1 804
2001	14	271	4 975	-	25	...	1 313
2002	195	377	5 089	10	20	...	1 210
2003	38	585	5 132	9	20	...	1 001
2004	73	271	4 712	3	13	...	1 224
2005	40	255	4 383	0	22	...	1 648
2006	48	213	3 991	0	7	...	1 362
2007	63	201	3 856	0	5	...	982
2008	63	241	3 771	0	8	...	1 109
2009	69	245	4 004	0	4	301	1 049
2010	120	116	3 886	0	5	238	872
2011	68	164	3 530	0	5	318	755
2012	79	175	3 055	-	3	191	738

Table A11 (continued)

	Egypt	France	France	Germany	Greece	Ireland	Isle of Man
Year / Species	***Solea solea***	***Solea solea***	***Solea senegalensis***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***
1990	135	7 533	-	2 296	3 261	597	6
1991	287	7 619	-	2 108	1 856	636	21
1992	360	9 467	-	1 881	2 108	547	7
1993	814	9 732	-	1 387	2 314	483	4
1994	710	10 238	-	1 749	1 834	573	5
1995	473	8 876	-	1 569	1 453	561	12
1996	751	7 338	-	685	1 235	463	4
1997	1 309	7 281	-	513	1 169	483	5
1998	1 034	7 073	-	786	745	526	3
1999	1 728	8 402	13	1 462	619	492	1
2000	3 502	8 447	51	1 291	687	376	1
2001	3 175	7 828	14	959	562	375	1
2002	2 756	7 316	27	771	752	334	0 0
2003	1 592	8 866	89	767	924	312	0 0
2004	1 254	8 194	31	967	860	292	0 0
2005	1 894	8 320	38	790	977	270	...
2006	2 592	8 094	50	519	1 419	229	...
2007	2 899	8 045	62	500	1 061	278	0 0
2008	3 366	7 061	37	549	775	214	0 0
2009	2 518	9 081	57	582	657	183	-
2010	2 702	8 230	59	563	573	203	-
2011	3 122	8 218	66	359	544	177	-
2012	2 063	7 635	60	452	510 F	216	-

Table A11 (continued)

	Israel	Italy	Libya	Malta	Morocco	Netherlands	Norway	Portugal
Year / Species	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***
1990	15 F	5 959	...	0 0	883	18 674	-	964
1991	13 F	12 716	...	0 0	912	18 928	-	951
1992	10	15 413	...	0 0	1 157	18 681	-	1 023
1993	9	12 386	...	0 0	1 215	22 014	-	287
1994	100	12 526	...	0 0	1 407	22 925	-	420
1995	100	6 065	...	0 0	1 545	20 927	-	235
1996	...	3 597	...	0 0	1 340	15 563	-	167
1997	...	3 085	...	0 0	1 675	10 370	-	151
1998	...	2 638	...	0 0	1 543	15 308	-	113
1999	...	2 252	...	0 0	2 622	16 329	-	121
2000	...	2 165	...	0 0	5 952	15 343	198	152
2001	...	2 966	...	0 0	3 788	13 737	88	201
2002	...	2 866	...	-	3 331	12 120	53	115
2003	...	3 760	...	-	2 092	12 469	129	124
2004	...	3 123	...	-	2 432	12 883	190	171
2005	...	2 498	...	-	3 074	10 926	89	280
2006	...	2 799	...	-	3 569	8 304	45	312
2007	...	2 565	...	0 0	3 465	10 368	13	264
2008	...	2 000	...	-	3 290	9 459	22	334
2009	...	2 452	225	0 0	4 107	9 606	5	385
2010	...	2 248	220 F	-	3 322	8 773	5	400
2011	...	1 798	130 F	0 0	2 410	8 128	7	292
2012	...	2 081	150 F	9	2 271	9 085	9	396

Table A11 (continued)

	Romania	Slovenia	Spain	Sweden	Tunisia	Turkey	UK	Totals
Year / Species	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***	
1990	-	-	1 652	81	644	-	4 359	54 675
1991	-	-	1 618	100	647	-	4 486	61 153
1992	-	2	1 912	107	751	-	3 794	64 773
1993	-	9	753 F	138	572	-	3 433	64 224
1994	3	7	702 F	94	493	-	3 589	66 553
1995	-	2	689 F	89	327	-	3 530	55 289
1996	-	1	574	61	569	-	3 022	43 026
1997	-	1	553	52	642	-	2 671	36 332
1998	4	1	5 783	41	480	-	2 561	44 132
1999	5	1	248	43	425	-	2 808	43 782
2000	6	2	994	30	402	-	2 443	48 670
2001	9	3	508	20	456	-	2 720	44 008
2002	6	4	470	15	454	-	2 574	40 865
2003	13	8	427	10	486	-	2 755	41 608
2004	13	7	394	16	438	-	2 648	40 209
2005	9	6	535	31	498	-	2 330	38 913
2006	-	6	411	38	550	-	2 529	37 087
2007	-	9	331	45	521	810	2 946	39 289
2008	-	7	384	36	469	748	2 378	36 321
2009	-	11	372	37	448	882	2 361	39 641
2010	-	8	458	46	463	1 062	2 228	36 800
2011	-	13	423	48	458	829	2 201	34 063
2012	-	9	363	31	445	792	1 988	32 806

Source: FAO, 2014.

AQUACULTURE

Table A12. Sole: aquaculture production (tonnes)

	Algeria	France	Greece	Italy	Portugal	Spain	Spain	Tunisia	Totals
Year / Species	***Solea solea***	***Solea senegalensis***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea solea***	***Solea senegalensis***	***Solea solea***	
1990	1	-	-	-	2	7	-	1	11
1991	1	-	-	-	3	9	-	0	13
1992	0	-	-	-	5	13	-	0	18
1993	1 F	-	-	-	4	12	-	0	17
1994	1 F	-	-	-	2	12	-	0	15
1995	0	-	-	-	5	25	-	0	30
1996	0	-	-	-	8	23	-	0	31
1997	0	-	-	-	7	18	-	0	25
1998	0	-	-	-	10	12	-	-	22
1999	0	-	-	-	5	14	-	-	19
2000	0	-	-	-	10	13	-	-	23
2001	0	-	-	-	17	43	-	-	60
2002	0	-	-	-	6	4	-	-	10
2003	-	-	-	-	4	20	-	-	24
2004	-	-	-	-	4	70	-	-	74
2005	-	-	-	-	11	-	8	-	19
2006	-	-	-	-	9	-	32	-	41
2007	-	-	-	-	8	11	36	-	55
2008	-	-	-	19.23	13	-	60	-	92.23
2009	-	-	-	14	14	1.53	63.38	-	92.91
2010	0.08 F	150 F	-	15	13.4	96.7	73.7	-	348.88
2011	-	150 F	2.1	0.5	3.6	64.95	84.76	-	305.92
2012	-	200 F	2 F	1 F	44.9	-	95.3	-	343.2

Source: FAO, 2014.

Table A13. Sole: total annual production (tonnes)

Year	Capture	Aquaculture	Total
1990	54 675	11	54 686
1991	61 153	13	61 166
1992	64 773	18	64 791
1993	64 224	17	64 241
1994	66 553	15	66 568
1995	55 289	30	55 319
1996	43 026	31	43 057
1997	36 332	25	36 357
1998	44 132	22	44 154
1999	43 782	19	43 801
2000	48 670	23	48 693
2001	44 008	60	44 068
2002	40 865	10	40 875
2003	41 608	24	41 632
2004	40 209	74	40 283
2005	38 913	19	38 932
2006	37 087	41	37 128
2007	39 289	55	39 344
2008	36 321	92	36 413
2009	39 641	93	39 734
2010	36 800	349	37 149
2011	34 063	306	34 369
2012	32 806	343	33 149

Source: Own elaboration from FAO (2014) data.

Table A14. Sole: weight curve - development in weight, feeding and feed cost over time

Month	Weight (gram)	Mortality rate (%)	Survival fraction = (100 - mortality rate) *001	No of fish * survival fraction	Weight (tonnes) = Weight by the No of fish	Change in weight	Feed (tonnes) = Change in weight * conversion factor (1.1)	Feed cost = feed x Price (1.40) (€1 000)
0	5	1	0.99	1 100 000	5.5	10.8	11.9	16.7
1	15	1	0.99	1 089 000	16.3	16	17.6	24.7
2	30	0.5	0.995	1 078 110	32.3	15.9	17.5	24.5
3	45	0.5	0.995	1 072 719.5	48.3	15.8	17.3	24.3
4	60	0.5	0.995	1 067 355.9	64	15.6	17.2	24
5	75	0.5	0.995	1 062 019.1	79.7	15.5	17	23.8
6	90	0.5	0.995	1 056 709	95.1	15.3	16.8	23.6
7	105	0.5	0.995	1 051 425.4	110.4	20.4	22.4	31.4
8	125	0.5	0.995	1 046 168.3	130.8	25.4	27.9	39.1
9	150	0.5	0.995	1 040 937.5	156.1	30.3	33.3	46.6
10	180	0.5	0.995	1 035 732.8	186.4	35.1	38.7	54.1
11	215	0.5	0.995	1 030 554.1	221.6	24.5	27	37.8
12	240	0.5	0.995	1 025 401.3	246.1	24.3	26.7	37.4
13	265	0.5	0.995	1 020 274.3	270.4	26.1	28.7	40.1
14	292	0.5	0.995	1 015 173	296.4	16.7	18.4	25.7
15	310	0.5	0.995	1 010 097.1	313.1	15.5	17.1	23.9
16	327	0.5	0.995	1 005 046.6	328.7	11.4	12.5	17.5
17	340	0	1	1 000 021.4	340	10	11	15.4
18	350	0	1	1 000 021.4	350	-	-	-
Sum								530.5

EXTERNAL TRADE

Table A15. Sole: total EU imports, 1995–2011 (tonnes)

Commodity	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Common sole, fresh or chilled	24 964	20 424	14 686	16 866	23 229	22 565	19 680	18 910	18 231
Common sole, frozen	15 070	15 730	14 866	14 604	10 939	13 557	15 580	13 348	14 258
Lemon sole, frozen	43	126	124	408	247	254	365	318	216
Total imports	**40 077**	**36 280**	**29 676**	**31 878**	**34 415**	**36 376**	**35 625**	**32 576**	**32 705**

Commodity	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Common sole, fresh or chilled	21 187	18 797	16 421	18 112	16 652	16 239	25 863	14 132
Common sole, frozen	12 383	12 868	14 485	15 197	9 873	10 439	9 329	7 146
Lemon sole, frozen	246	285	389	522	443	503	627	282
Total imports	**33 816**	**31 950**	**31 295**	**33 831**	**26 968**	**27 181**	**35 819**	**21 560**

Source: FAO.

Table A16. Sole: total EU exports, 1995–2011 (tonnes)

Commodity	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Common sole, fresh or chilled	23 143	19 631	15 448	15 758	23 699	20 943	16 381	18 454	19 713
Common sole, frozen	13 190	10 681	8 885	8 346	10 335	8 877	7 924	8 308	9 406
Lemon sole, frozen	410	415	542	624	502	410	661	601	552
Total, export	**36 743**	**30 727**	**24 875**	**24 728**	**34 536**	**30 230**	**24 966**	**27 363**	**29 671**

Commodity	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Common sole, fresh or chilled	21 044	18 029	15 163	16 551	16 775	16 173	15 850	13 788
Common sole, frozen	9 703	9 400	8 498	8 823	6 062	5 816	5 520	6 874
Lemon sole, frozen	408	440	439	537	347	301	447	418
Total, export	**31 155**	**27 869**	**24 100**	**25 911**	**23 184**	**22 290**	**21 817**	**21 080**

Source: FAO.

Table A17. Imports of Common sole, fresh or chilled, five largest countries, 2000–2011 (tonnes)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Spain	6 098	5 653	5 350	5 582	7 160	5 909	5 265	6 126	5 671	5 161	7 894	4 302
Italy	5 798	4 989	5 014	4 574	4 907	4 744	4 047	3 961	4 105	4 393	4 323	4 296
Netherlands	3 392	3 678	3 022	3 417	3 629	3 692	3 477	4 917	3 726	3 093	10 501	2 567
France	4 352	3 867	3 857	3 185	4 013	2 822	1 721	1 557	1 915	2 385	1 953	1 550
UK	474	350	577	377	362	338	821	624	287	177	242	546
Total EU	**22 565**	**19 680**	**18 910**	**18 231**	**21 187**	**18 797**	**16 421**	**18 112**	**16 652**	**16 239**	**25 863**	**14 132**

[a] As of 2011.

Table A18. Imports of Common sole, frozen, five largest countries, 2000–2011 (tonnes)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Spain	7 190	8 375	7 346	8 091	7 331	7 334	8 545	9 090	5 971	6 620	5 105	3 194
Italy	4 862	5 569	4 609	4 652	3 385	3 536	3 711	3 951	2 506	2 605	2 643	2 522
France	626	617	519	705	775	638	596	397	449	363	415	488
Portugal	249	186	177	181	192	415	847	476	349	285	277	346
Germany	244	410	277	280	248	268	287	490	254	188	249	250
Total EU	**13 557**	**15 580**	**13 348**	**14 258**	**12 383**	**12 868**	**14 485**	**15 197**	**9 873**	**10 439**	**9 329**	**7 146**

Table A19. Imports of Lemon sole, frozen, five largest countries, 2000–2011 (tonnes)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Spain	95	165	158	128	111	165	199	349	260	149	147	127
Portugal	17	18	37	51	79	80	132	153	177	57	100	85
UK	-	-	-	-	-	-	1	-	-	115	67	22
Denmark	-	-	-	-	-	-	-	-	-	-	14	20
Belgium	-	0 0	0 0	0 0	27	0 0	-	4	1	-	5	13
Total, EU	**254**	**365**	**318**	**216**	**246**	**285**	**389**	**522**	**443**	**503**	**627**	**282**

Table A20. Exports of Common sole, fresh or chilled, five largest countries, 2000–2011 (tonnes)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Netherlands	10 253	6 142	7 408	7 630	9 624	7 226	5 064	5 813	6 499	6 469	5 731	4 696
France	2 832	2 709	2 935	2 880	2 678	2 518	2 513	2 844	3 304	2 553	2 540	2 686
Belgium	2 475	2 354	2 845	3 860	3 153	2 984	2 955	2 677	2 821	2 743	2 502	2 144
UK	2 298	2 457	2 092	2 012	1 832	1 865	1 880	2 203	1 585	1 739	1 715	1 574
Denmark	2 280	1 782	1 868	2 188	2 634	2 382	1 942	1 707	1 483	1 482	1 415	1 242
EU, total	**20 943**	**16 381**	**18 454**	**19 713**	**21 044**	**18 029**	**15 163**	**16 551**	**16 775**	**16 173**	**15 850**	**13 788**

Table A21. Exports of Common sole, frozen, five largest countries, 2000–2011 (tonnes)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Netherlands	5 659	4 830	5 134	6 228	5 668	5 572	4 934	5 813	3 575	3 504	2 882	4 882
Spain	764	715	905	663	757	971	1 116	1 111	856	560	995	791
Belgium	748	960	658	1 095	1 423	1 057	856	610	439	443	452	351
Germany	1 041	836	676	687	911	735	489	477	494	551	543	341
Italy	391	315	500	506	649	501	347	399	384	377	338	224
Total, EU	**8 877**	**7 924**	**8 308**	**9 406**	**9 703**	**9 400**	**8 498**	**8 823**	**6 062**	**5 816**	**5 520**	**6 874**

Table A22. Exports of Lemon Sole, fresh or chilled, five largest countries, 2000–2011 (tonnes)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
UK	388	411	397	409	373	404	404	500	300	300	300	400
Portugal	-	-	-	-	-	-	10	2	2	-	-	9
Denmark	-	13	-	-	1	-	2	-	-	-	13	7
Germany	-	-	-	-	-	-	-	-	-	-	-	1
Spain	-	120	166	130	1	28	14	33	45	-	-	1
Total	**410**	**661**	**601**	**552**	**408**	**440**	**439**	**537**	**347**	**301**	**447**	**418**

PRICE AND MARKET DATA

Table A23. Average price of sole landed by UK vessels in the UK, 2000–2013, live weight

Year	£ per kg (live weight)	€ per kg (live weight)
2000	5.95	9.77
2001	6.29	10.12
2002	6.1	9.70
2003	6.22	8.99
2004	6.45	9.51
2005	7.06	10.33
2006	7.74	11.35
2007	7.38	10.79
2008	7.15	9.00
2009	7.32	8.22
2010	8.24	9.61
2011	8.58	9.89
2012	8.12	10.02
2013	7.30	8.60

Source: Marine Management Organisation (2014) for UK prices. GBP prices have been converted to EUR by use of annual average exchange rates: http://fxtop.com (accessed 23/04/14).

Table A24. The Netherlands: sole prices by size class, nominal prices

	Size Class				
Class	**1**	**2**	**3**	**4**	**5**
2003	13.33	13.85	12.55	8.83	6.83
2004	15.07	15.10	10.84	7.72	6.21
2005	15.36	13.59	11.52	10.07	8.45
2006	16.32	16.31	15.32	12.74	10.16
2007	18.98	19.70	15.22	9.88	7.30
2008	17.11	15.39	10.57	8.89	8.03
2009	13.65	12.06	11.08	9.77	8.06
2010	14.05	12.91	13.91	11.07	8.99
2011	13.47	14.20	14.03	10.03	8.18
2012	19.57	18.24	12.32	8.64	7.16
2013	12.94	11.37	9.77	7.41	6.24

Source: Wageningen UR database.

Table A25. Sole: monthly prices in 2013, UK vessels in UK ports

January	8.71
February	8.70
March	8.08
April	5.96
May	4.77
June	7.31
July	6.35
August	5.80
September	6.69
October	7.21
November	7.50
December	7.95

Source**:** Marine Management Organisation (2014)**.**

Table A26. Average annual ex-vessel sole price by fishing gear in Catalonia, Spain, 2000–2013

Year	Long-line	Trawl
2001	17.51	15.61
2002	19.78	17.44
2003	22.27	17.08
2004	20.58	17.04
2005	21.51	16.53
2006	22.96	19.80
2007	25.23	19.68
2008	22.06	19.96
2009	22.89	21.08
2010	24.04	20.74
2011	17.83	19.87
2012	19.59	19.67
2013	17.50	18.01

Source**:** Guillen and Franquesa (2015).

Table A27. Sole: landings at the Vigo fish market, January 2010–December 2013

Month	Quantity (kg)	Price (€/kg)	Month	Quantity (kg)	Price (€/kg)
Jan 2010	5 544.90	13.3	Jan 2012	6 924.00	12.5
Feb 2010	4 174.40	10.9	Feb 2012	3 816.60	12.8
Mar 2010	3 830.40	16.0	Mar 2012	2 452.40	14.2
Apr 2010	4 872.20	15.5	Apr 2012	2 749.90	19.1
May 2010	3 185.90	15.6	May 2012	5 179.10	17.1
Jun 2010	3 469.30	17.8	Jun 2012	4 528.80	17.6
Jul 2010	3 112.80	19.0	Jul 2012	4 580.30	19.7
Aug 2010	2 295.30	20.6	Aug 2012	3 828.60	18.9
Sep 2010	2 078.00	17.7	Sep 2012	4 081.90	17.7
Oct 2010	3 883.00	16.8	Oct 2012	4 798.50	16.0
Nov 2010	5 055.10	14.6	Nov 2012	5 215.10	13.9
Dec 2010	3 886.80	20.5	Dec 2012	4 404.00	15.8
Jan 2011	4 033.90	13.7	Jan 2013	4 001.10	15.5
Feb 2011	4 057.70	13.2	Feb 2013	3 575.00	12.9
Mar 2011	4 556.30	14.0	Mar 2013	3 342.10	17.6
Apr 2011	3 460.80	16.7	Apr 2013	7 791.20	14.1
May 2011	4 835.00	15.8	May 2013	8 972.20	13.6
Jun 2011	4 056.70	17.5	Jun 2013	8 533.40	14.5
Jul 2011	2 965.20	19.7	Jul 2013	5 408.30	15.8
Aug 2011	5 465.70	20.1	Aug 2013	3 089.90	17.2
Sep 2011	2 832.90	18.8	Sep 2013	3 855.70	15.1
Oct 2011	5 732.40	16.9	Oct 2013	5 051.60	13.9
Nov 2011	8 883.60	15.1	Nov 2013	5 756.90	13.0
Dec 2011	6 143.70	17.4	Dec 2013	6 283.90	12.6

Source: Xunta de Galicia (2014).

Table A28. Imports and exports to Spain of fresh or chilled sole, 2000–2013

Year	Imports		Export	
	Quantity (tonnes)	Price (€/kg)	Quantity (tonnes)	Price(€/kg)
2000	6 438.6	7.54	176.3	3.35
2001	6 408.9	7.25	167	4.98
2002	6 361.6	8.36	607.6	1.65
2003	5 922	8.62	155.4	4.91
2004	7 497.1	8.19	208.6	6.22
2005	6 041.5	9.87	185.7	5.44
2006	5 380.1	10.71	46.9	10.35
2007	6 331.3	9.27	56.1	10.14
2008	5 851.4	9.18	50.2	9.21
2009	5 188	9.15	50	14.44
2010	7 927	5.50	517.7	6.36
2011	4 324.9	9.55	288.5	8.47
2012	4 768.6	8.37	312.3	7.85
2013	4 669	8.13	738.7	5.64

Source: Agencia Tributaria **(**2014).

Table A29. Imports and exports to Spain of frozen sole, 2000–2013

Year	Imports		Export	
	Quantity (tonnes)	Price (€/kg)	Quantity (tonnes)	Price (€/kg)
2000	7 507.3	3.47	833.7	4.02
2001	8 572.4	4.55	716.8	4.65
2002	7 547.3	3.91	910.2	3.63
2003	8 137.7	3.79	718.8	3.58
2004	7 340.9	3.87	754.4	3.52
2005	7 378.1	3.89	1 024.5	2.63
2006	8 580.4	4.14	1 143	3.22
2007	9 082.2	4.18	1 119.2	3.08
2008	5 990.3	3.92	849.7	2.54
2009	6 596.8	3.71	551.4	3.57
2010	5 060.7	3.84	983	3.06
2011	3 192.7	5.14	791.5	3.97
2012	3 585.8	5.11	402.4	5.97
2013	2 402.8	4.85	338.4	5.09

Source: Agencia Tributaria **(**2014).

Table A30. Annual sales at Barcelona's wholesale market, MercaBarna

Year	Quantity (kg)		Value (€)		Price (€/kg)	
	Sole fresh	Sole frozen	Sole fresh	Sole frozen	Sole fresh	Sole frozen
2006	1 781 622	287 234	26 104 433	1 586 807	14.7	5.5
2007	1 826 465	242 920	23 175 804	1 726 381	12.7	7.1
2008	1 784 992	247 238	21 030 195	1 731 565	11.8	7.0
2009	1 614 357	248 524	20 335 013	1 687 159	12.6	6.8
2010	1 374 990	278 105	18 768 751	1 576 201	13.7	5.7
2011	1 491 208	244 069	19 275 170	1 761 320	12.9	7.2
2012	,291 499	191 454	14 591 122	1 451 993	11.3	7.6
2013	1 355 232	182 755	13 550 207	1 182 284	10.0	6.5

Source: MercaBarna (2014).

Table A31. Annual sales at Madrid's wholesale market, MercaMadrid

	Quantity (kg)				
Year	**Sole large fresh**	**Sole medium fresh**	**Sole small fresh**	**Sole aquaculture fresh**	**Sole frozen**
2002	161 446	645 949	807 554		392 312
2003	140 706	569 341	713 737		197 883
2004	157 086	533 392	1 230 122		185 236
2005	98 797	343 553	849 351		725 984
2006	31 675	239 525	662 738		1 145 592
2007	10 207	204 489	616 774		1 038 231
2008	64 760	329 650	924 090		1 106 682
2009	145 928	631 656	695 065		1 287 940
2010	201 103	737 196	402 067		1 003 827
2011	171 326	628 206	342 650		731 974
2012	148 622	505 497	221 874	6,648[a)]	426 831
2013	124 528	619 974	413 136	11,649	804 707

[a)] Incomplete data.
Source: MercaMadrid (2014).

Table A32. Annual sales at Madrid's wholesale market, MercaMadrid

	Value (€)				
Year	**Sole large fresh**	**Sole medium fresh**	**Sole small fresh**	**Sole aquaculture fresh**	**Solefrozen**
2002	3 233 047	9 749 494	6 534 489		2 828 570
2003	2 539 901	7 856 289	6 082 046		1 426 736
2004	3 303 889	8 006 942	9 703 815		1 338 886
2005	2 128 083	4 952 347	7 924 844		5 669 935
2006	770 091	4 017 499	6 929 104		8 947 074
2007	252 902	2 993 549	5 521 840		6 872 434
2008	1 405 670	5 385 631	9 074 987		6 983 163
2009	3 628 841	10 666 246	7 261 885		8 126 901
2010	3 738 692	9 999 177	3 265 425		6 334 148
2011	3 205 921	8 316 690	3 055 564		4 618756
2012	3 313 742	8 086 856	2 449 560	86 983[a)]	2 693 304
2013	3 040 217	11 175 194	4 559 077	142 661	5 077 701

[a)] Incomplete data.
Source: MercaMadrid (2014).

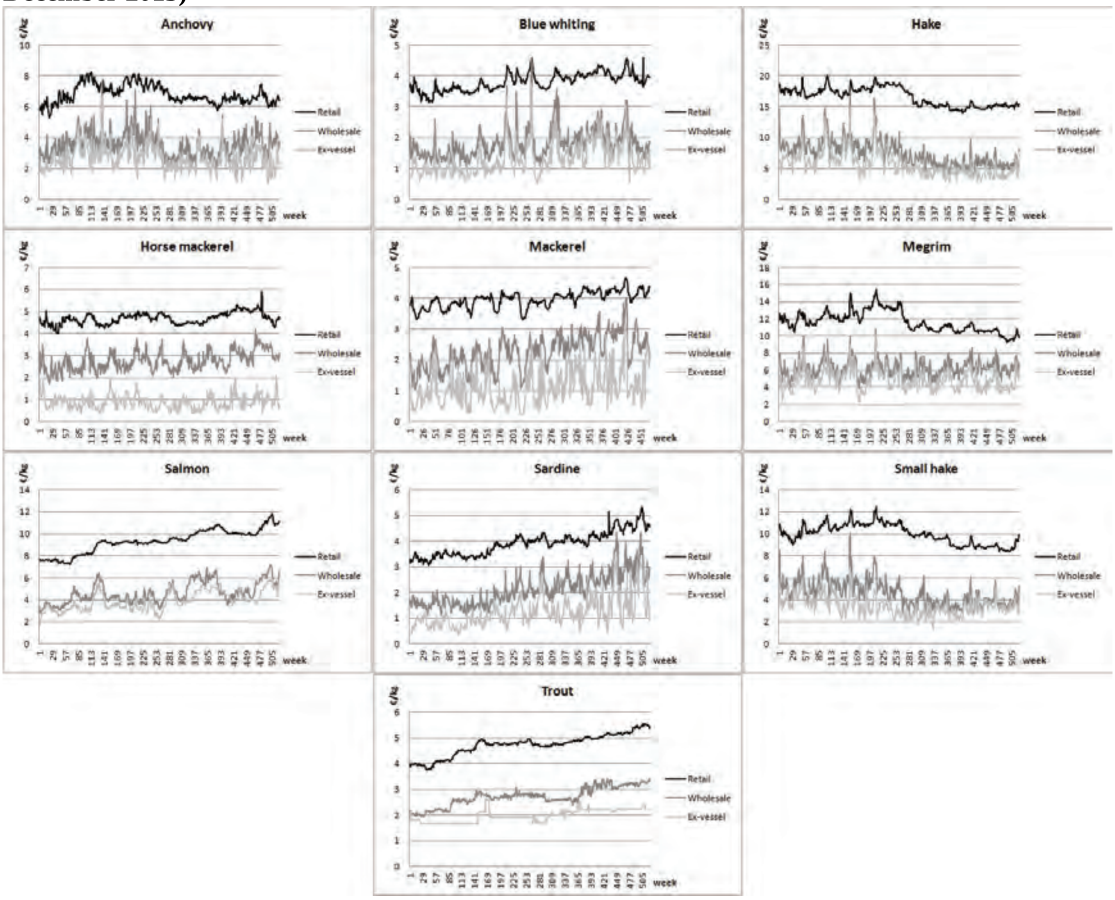
Table A33. Annual sales at Madrid's wholesale market, MercaMadrid

	€/kg)				
Year	**Sole large fresh**	**Sole medium fresh**	**Sole small fresh**	**Sole aquaculture fresh**	**Sole frozen**
2002	20.0	15.1	8.1		7.2
2003	18.1	13.8	8.5		7.2
2004	21.0	15.0	7.9		7.2
2005	21.5	14.4	9.3		7.8
2006	24.3	16.8	10.5		7.8
2007	24.8	14.6	9.0		6.6
2008	21.7	16.3	9.8		6.3
2009	24.9	16.9	10.4		6.3
2010	18.6	13.6	8.1		6.3
2011	18.7	13.2	8.9		6.3
2012	22.3	16.0	11.0	13.1	6.3
2013	24.4	18.0	11.0	12.2	6.3

[a)] Incomplete data.

Source: MercaMadrid (2014).

Figure A1. Price trends for various species (first week 5–10 January 2004; last week 23–28 December 2013)



*Wholesale price is weighted price for all wholesale markets in Spain.
Source: MAGRAMA (2014).

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